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465 OSCILLOSCOPE

Introduction

This Operators Handbook is intended to give the necessary information to allow a user to become familiar with the instrument's power requirements, functions of controls and connectors, and also provides a few methods of making several different measurements of electrical phenomena. Also included is a rudimentary procedure for checking basic instrument calibration.

Operating Voltage

CAUTION

This instrument is designed for operation from a power source with its neutral at or near earth (ground) potential with a separate safety-earth conductor. It is not intended for operation from two phases of a multi-phase system, or across the legs of a single-phase three-wire system.

This instrument can be operated from either a 115-volt or a 230-volt nominal line voltage source, 48 to 440 hertz. The line voltage selector switch in the instrument converts the instrument from one nominal operating voltage to the other. The regulating range selector assembly on the instrument rear panel selects one of three regulating ranges for each nominal line voltage, and also contains the line fuses for overload protection for both nominal line voltages. To select the correct nominal line voltage and regulating range, proceed as follows:

1. Disconnect the instrument from the power source.

2. To convert from 115-volts nominal to 230-volts nominal line voltage, set the selector switch to the 230-volts position (toward the rear of the instrument). Change the line-cord plug to match the power source or use a 115-to-230 volt adapter.

NOTE

Color-coding of the cord conductors is as follows (in accordance with National Electrical Code):

Line	*Black*
Neutral	*White*
Safety earth (ground)	*Green*

3. To change regulating ranges, loosen the two captive screws which hold the cover onto the regulating range selector assembly; then pull to remove the cover.

4. Pull out the range selector switch bar (see Fig. 1). Slide the bar to the desired position and plug it back in. Select a range which is centered about the average line voltage to which the instrument is to be connected (see Table 1).

TABLE 1

Regulating Ranges

Range Selector Switch Position	Regulating Range	
	115-Volts Nominal	230-Volts Nominal
LO (Switch bar in lower holes)	99 to 121 volts	198 to 242 volts
M (switch bar in middle holes)	104 to 126 volts	208 to 252 volts
HI (switch bar in upper holes)	108 to 132 volts	216 to 264 volts

5. Re-install the cover and tighten the two captive screws.

6. Before applying power to the instrument, check that the line voltage selector switch and the indicating tabs on the regulating range selector assembly are in the correct positions for the line voltage the instrument will be operated on.

CAUTION

This instrument may be damaged if operated with the line voltage selector switch or the regulating range selector assembly set to incorrect positions for the line voltage applied.

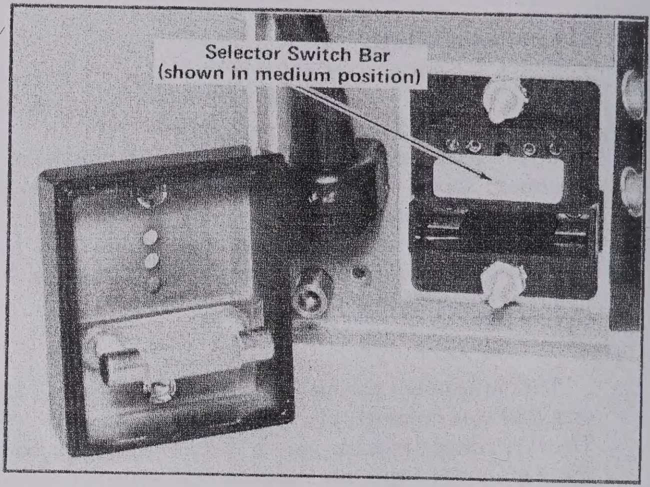


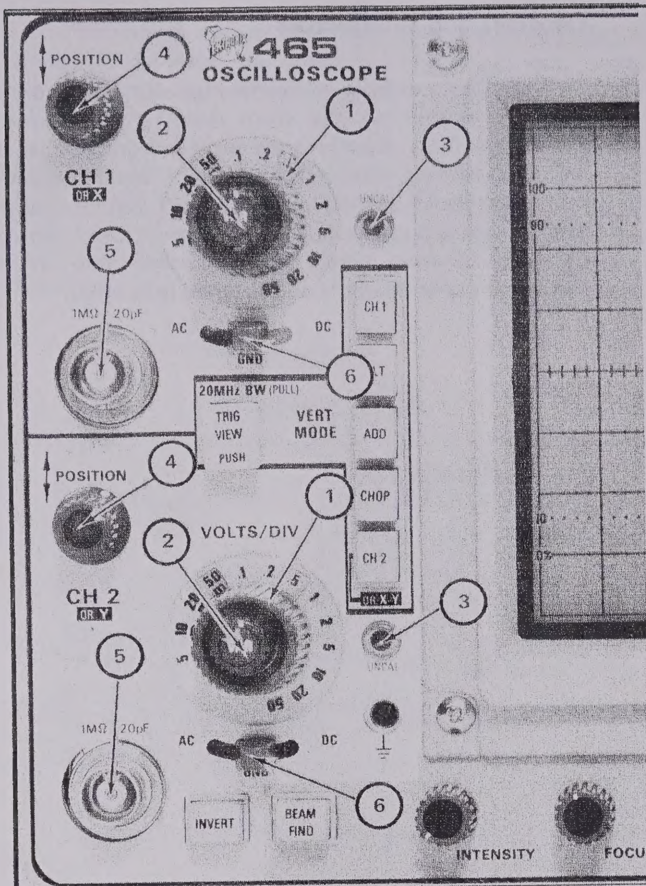
Fig. 1. Power supply regulating range selector.

The 465 is designed to be used with a three-wire AC power system. If a three- to two-wire adapter is used to connect this instrument to a two-wire AC power system, be sure to connect the ground lead of the adapter to earth (ground). Failure to complete the ground system may allow the chassis of this instrument to be elevated above ground potential and pose a shock hazard.

The feet on the rear panel provide a convenient cord wrap to store the power cord when not in use.

Controls and Connectors

The major controls and connectors for operation of the 465 are located on the front panel of the instrument. Several auxiliary functions are provided on the rear panel. To make full use of the capabilities of this instrument, the operator should be familiar with the function and use of each of these controls and connectors. A brief description of each is given here. Some of the more important instrument specifications are included here also.



1. CH 1 and CH 2 VOLTS/DIV—selects the vertical deflection factor in a 1-2-5 sequence (VARiable control must be in the calibrated detent for the indicated deflection factor). Calibrated position accuracy is within 3%.

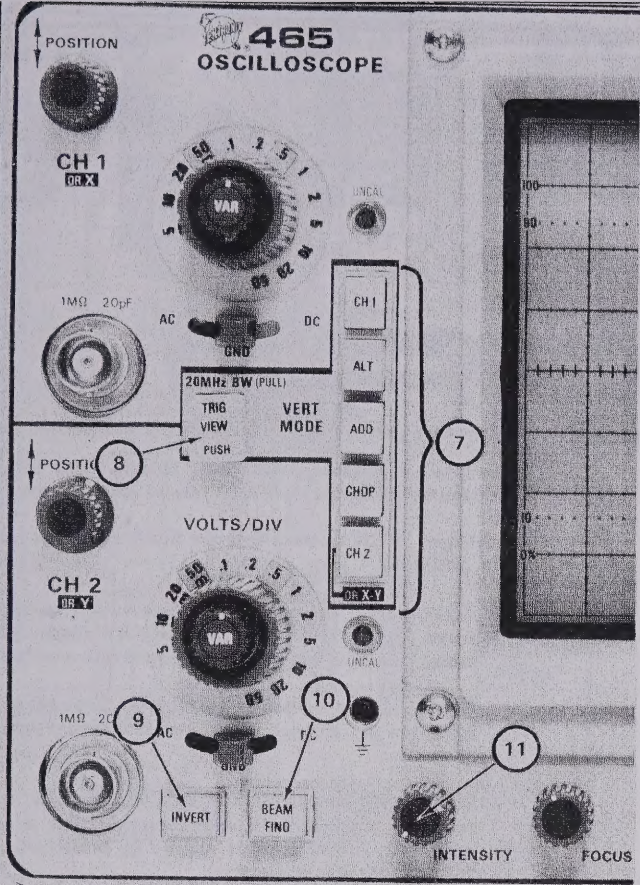
2. VARiable—provides continuously variable uncalibrated deflection factors between the calibrated settings of the VOLTS/DIV switch.

3. UNCALibrated—indicates when the VARiable VOLTS/DIV control is out of the calibrated detent position and the vertical deflection factor is uncalibrated.

4. POSITION—positions the display vertically.

5. CH 1 OR X and CH 2 OR Y—input connectors for application of external signals to the inputs of the vertical amplifier. In the X-Y mode of operation, the signal connected to the CH 1 OR X connector provides horizontal deflection and the signal connected to the CH 2 OR Y connector provides the vertical deflection. Input impedance is 1 megohm paralleled by approximately 20 picofarads. Minimum bandwidth in the normal mode of operation is DC to at least 100 MHz. X-axis bandwidth in X-Y operation is DC to 4 megahertz.

6. AC-GND-DC—selects the method used to couple a signal to the input of the vertical amplifier. In the AC position, signals are capacitively coupled to the vertical amplifier. The DC component of the input signal is blocked. Low frequency −3 dB point is about 10 Hz. In the GND position, the input of the vertical amplifier is disconnected from the input connector and grounded. Allows precharging of the input coupling capacitor. In the DC position, all components of the input signal are passed to the input amplifier.



7. VERTical MODE—selects mode of operation for vertical amplifier system.

   CH 1: Channel 1 only is displayed.

   ALTernate: Dual-trace display of the signals of both channels. Display is switched between channels at the end of each sweep.

   ADD: Signals applied to the CH 1 and CH 2 input connectors are algebraically added, and the algebraic sum is displayed on the CRT. The INVERT switch in Channel 2 allows the display to be CH 1 plus CH 2 or CH 1 minus CH 2.

   CHOP: Dual-trace display of the signals of both channels. Display is switched between channels at a repetition rate of approximately 250 kHz.

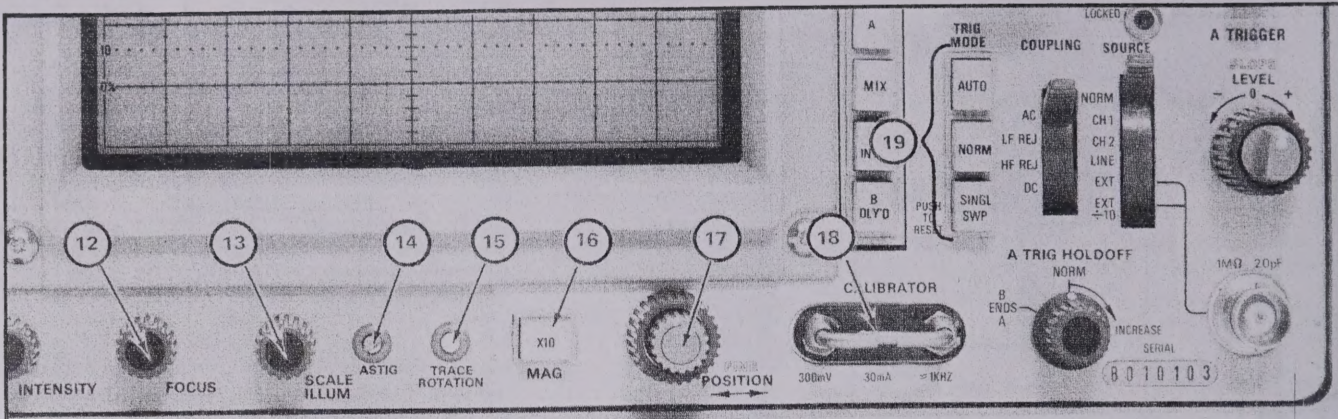
   CH 2: Channel 2 only is displayed. Must be selected in X-Y operation.

8. 20 MHz BW/TRIG VIEW—Dual purpose switch that limits the bandwidth of the vertical amplifier system to approximately 20 MHz when pulled, or causes signal connected to A External Input connector to be displayed on the CRT when pressed.

9. INVERT—Channel 2 display is inverted in the INVERT (button in) position.

10. BEAM FINDer—compresses the display to within the graticule area independently of display position or applied signals and provides a visible viewing level.

11. INTENSITY—controls brightness of the CRT display.



12. FOCUS—adjusts for optimum display definition.

13. SCALE ILLUMination—controls graticule illumination.

14. ASTIGmatism—screwdriver adjustment used in conjunction with the FOCUS control to obtain a well-defined display. Does not require readjustment in normal use.

15. TRACE ROTATION—adjusts trace to align with the horizontal graticule lines.

16. X10 MAGnifier—increases displayed sweep rate by a factor of 10. Extends fastest sweep rate to 5 nanoseconds/division. Calibrated magnified sweep accuracy is typically within 3%.

17. POSITION—positions the display horizontally.

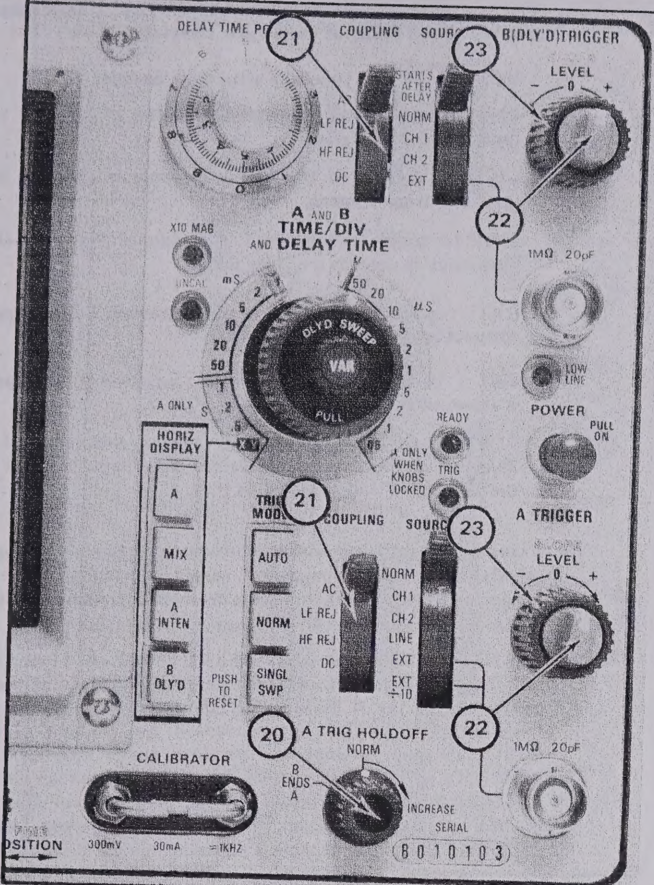
18. CALIBRATOR—a combination current loop/squarewave voltage output device. Provides a 30 mA (within 2%) squarewave current, 300 mV (within 1%) squarewave voltage signal with a repetition rate of approximately 1 kHz.

19. TRIGger MODE—determines the mode of trigger operation for A Sweep.

AUTOmatic: The sweep is initiated by the applied trigger signal. In the absence of an adequate trigger signal, the sweep free runs and provides a bright reference trace.

NORMal: The sweep is initiated by the applied trigger signal. In the absence of an adequate trigger signal, there is no trace.

SING SWP: when this pushbutton is pushed, A Sweep operates in the single sweep mode. After a sweep is displayed, further sweeps cannot be presented until the SING SWP button is pushed.



20. A TRIGger HOLDOFF—provides continuous control of time between sweeps. Allows triggering on aperiodic signals (such as complex digital words). In the fully clockwise position (B ENDS A), A sweep is reset at the end of B sweep to provide the fastest possible sweep repetition rate for delayed sweep presentations.

21. COUPLING—determines method used to couple signals to trigger generator circuit.

AC: Signals are capacitively coupled to the input of the trigger generator circuit. DC is rejected and signals below about 60 Hz are attenuated.

LF REJ: Signals are capacitively coupled to the input of the trigger circuit. DC is rejected and signals below about 50 kHz are attenuated.

HF REJ: Signals are capacitively coupled to the input of the trigger circuit. DC is rejected and signals below about 60 Hz and above about 50 kHz are attenuated.

DC: All components of a trigger signal are coupled to the input of the trigger circuit.

22. SLOPE—selects the slope of the trigger signal which starts the sweep.

+: Sweep can be triggered from the positive-going portion of a trigger signal.

−: Sweep can be triggered from the negative-going portion of a trigger signal.

23. LEVEL—selects the amplitude point on the trigger signal at which the sweep is triggered.

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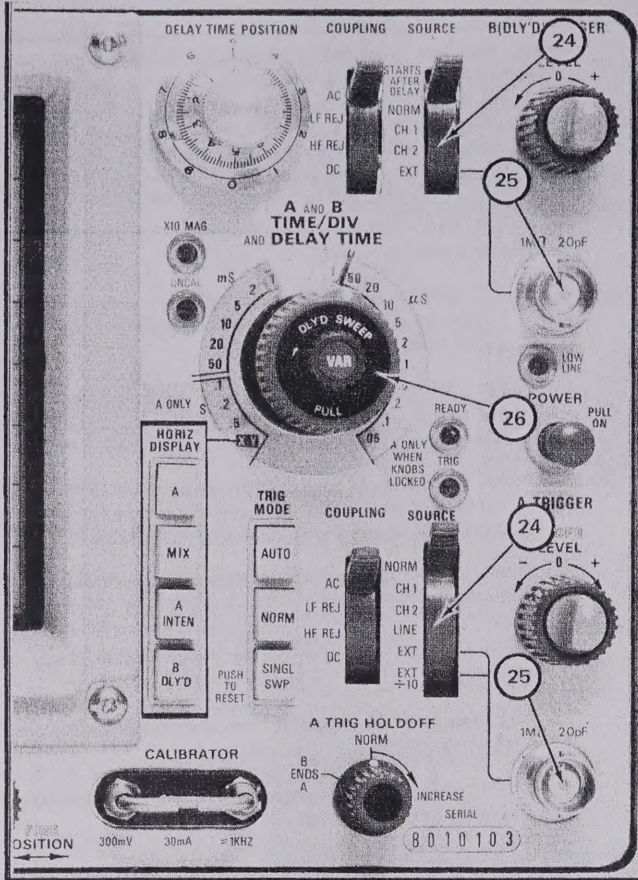


24. SOURCE—determines the source of the trigger signal coupled to the input of the trigger circuit.

NORMal: Trigger source is displayed signal(s).

CH 1: A sample of the signal available in Channel 1 is used as a trigger signal.

CH 2: A sample of the signal available in Channel 2 is used as a trigger signal.

LINE (A trigger circuit only): A sample of the power-line frequency is used as a trigger signal.

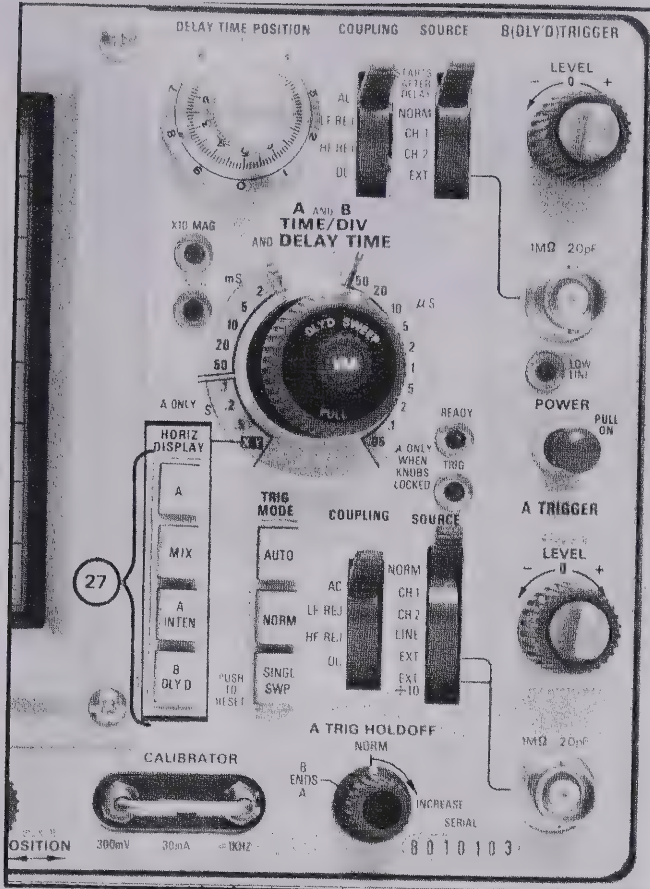
EXT: Signals connected to the External Trigger Input connectors are used for triggering.

EXT ÷ 10 (A trigger circuit only): External trigger signal is attenuated by a factor of 10.

STARTS AFTER DELAY (B trigger circuit only): B Sweep runs immediately after the delay time selected by the DELAY-TIME POSITION dial.

25. External Trigger Input—input connectors for external trigger signals. Nominal input signal level required for correct trigger operation is 50 millivolts from DC to approximately 25 MHz increasing to 150 millivolts at 100 MHz.

26. A AND B TIME/DIV AND DELAY TIME—A TIME/DIV switch (clear plastic flange) selects the sweep rate of the A sweep circuit for A Sweep only operation and selects the basic delay time (to be multiplied by DELAY TIME POSITION dial setting) for delayed sweep operation. B TIME/DIV switch selects sweep rate for the B sweep circuit for delayed sweep operation only. A VAR control must be in the calibrated detent for calibrated sweep rates. Calibrated unmagnified sweep accuracy typically within 2%.



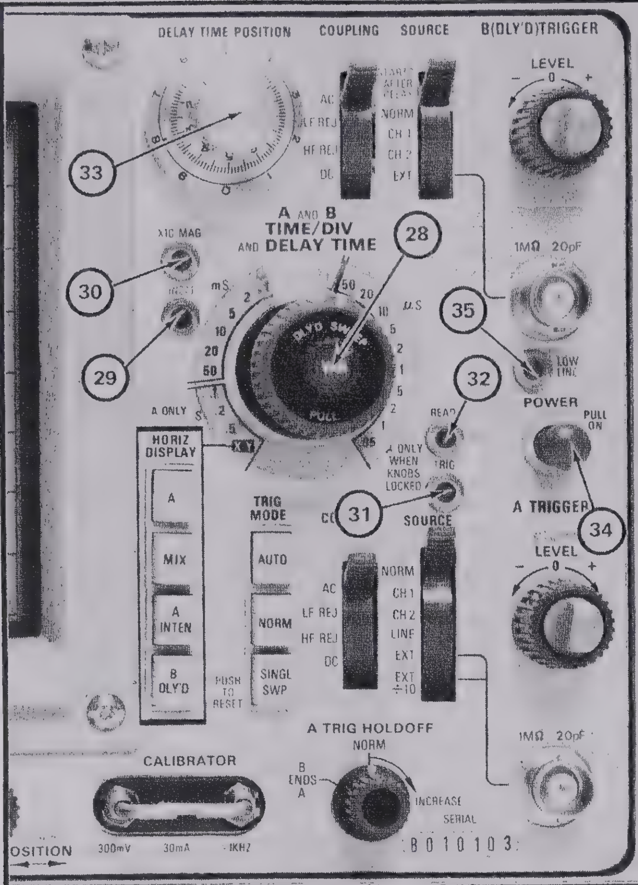
27. HORIZontal DISPLAY—determines mode of operation for horizontal deflection system.

A: Horizontal deflection provided by A Sweep at a sweep rate determined by the setting of the A TIME/DIV switch. B Sweep inoperative.

MIX: First part of the horizontal sweep displayed at a rate set by the A TIME/DIV switch and the latter part of the sweep at a rate set by the B TIME/DIV switch. Relative amounts of the display allocated to each of the two sweep rates are determined by the setting of the DELAY-TIME POSITION dial.

A INTEN: Sweep rate determined by the A TIME/DIV switch. An intensified portion appears on the display during the B sweep time. This switch position provides a check of the duration and position of the B sweep (delayed sweep) with respect to the delaying sweep (A).

B DLYD: Sweep rate determined by the B TIME/DIV switch with the delay time determined by the setting of the DELAY TIME (A TIME/DIV) switch and the DELAY-TIME POSITION dial.



28. **VARiable**—provides continuously variable sweep rates between the calibrated settings of the A TIME/DIV switch. Extends the slowest A sweep rate to at least 1.25 seconds/division. The A sweep rate is calibrated when the control is set fully clockwise to the calibrated detent.

29. **UNCAL**—light that indicates the A sweep rate is uncalibrated (VAR control out of the calibrated detent).

30. **X10 MAGnifier**—light that indicates the X10 magnifier is on.

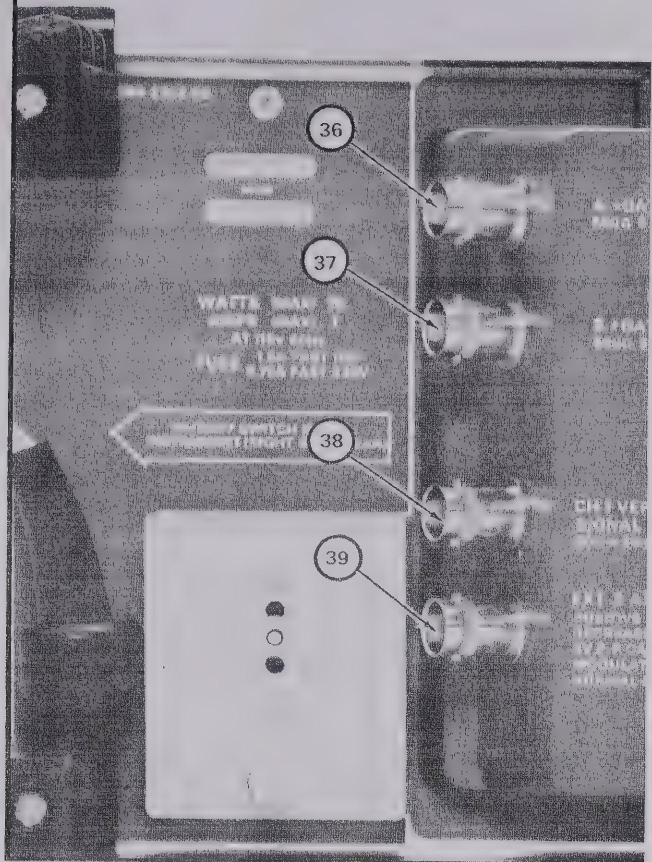
31. **TRIGgered**—light that indicates that A sweep is triggered and will produce a stable display.

32. **READY**—light that indicates A sweep is "armed" and, upon receipt of an adequate trigger signal, will present a single-sweep display.

33. **DELAY-TIME POSITION**—provides variable sweep delay from 0.20 to 10.20 times the delay time indicated by the A TIME/DIV switch.

34. **POWER**—turns instrument power on and off.

35. **LOW LINE**—light that indicates the applied line voltage is below the lower limit of the regulating range selected by the Regulating Range Selector assembly.



36. A +GATE—output connector provides a positive-going rectangular pulse coincident with the A sweep time.

37. B +GATE—output connector providing a positive-going rectangular pulse coincident with the B sweep time.

38. CH 1 VERT SIGNAL OUT—output connector providing a sample of the signal applied to the CH 1 input connector.

39. EXT Z-AXIS—input connector for intensity modulation of the CRT display. A 5-volt peak-to-peak signal from DC to 50 MHz will cause noticeable modulation at normal intensity.

APPLICATIONS

General

The following information describes the procedures and techniques for making basic measurements with a 465 Oscilloscope. These applications are not described in detail, since each application must be adapted to the requirements of the individual measurement. This instrument can also be used for many applications which are not described in this handbook. Contact your local TEKTRONIX Field Office or representative for assistance in making specific measurements with this instrument. Also, the following books describe oscilloscope measurement techniques which can be adapted for use with this instrument.

Czech, J., "Oscilloscope Measuring Techniques", Springer-Verlag, New York, 1965.

Golding, J. H., "Measuring Oscilloscope". Transatlantic, 1971.

Lenk, John D., "Handbook of Oscilloscopes", Prentice-Hall, Inc., Englewood Cliffs, N. J., 1968.

Roth, Charles H., "Use of the Oscilloscope", Prentice-Hall, Inc., Englewood Cliffs, N. J., 1970.

Certain portions of the instrument's calibration should be periodically checked to insure measurement accuracy. Prior to actually making a measurement, refer to the list of checks given in the section entitled "User's Calibration".

Peak-to-Peak Voltage Measurements—AC

1. Connect the signal to either input connector.

2. Set the VERT MODE switch to display the channel used.

3. Set the VOLTS/DIV switch to display about five divisions of the waveform.

4. Set the Input Coupling switch to AC.

NOTE

For low-frequency signals below about 10 hertz, use the DC position.

5. Set the A Trigger controls to obtain a stable display. Set the TIME/DIV switch to a position that displays several cycles of the waveform.

6. Turn the vertical POSITION control so the lower portion of the waveform coincides with one of the graticule lines below the center horizontal line, and the top of the waveform is on the viewing area. Move the display with the horizontal POSITION control so one of the upper peaks lies near the center vertical line (see Fig. 2).

7. Measure the divisions of vertical deflection from peak to peak. Make sure the VAR VOLTS/DIV control is in the calibrated detent.

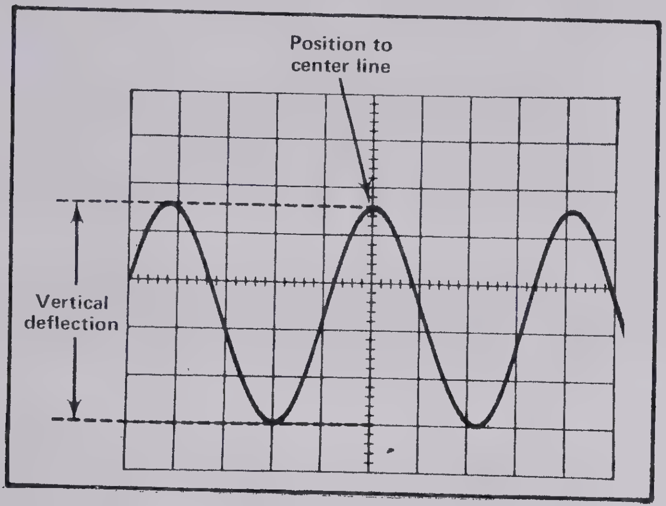


Fig. 2. Measuring peak-to-peak voltage of a waveform.

NOTE

This technique may also be used to make measurements between two points on the waveform rather than peak to peak.

8. Multiply the distance measured in step 7 by the VOLTS/DIV switch setting. Also include the attenuation factor of the probe, if using a probe that does not have a scale-factor switching connector.

Example. Assume a peak-to-peak vertical deflection of 4.6 divisions (see Fig. 2) with a VOLTS/DIV switch setting of .5.

Using the formula:

$$\text{Volts Peak to Peak} = \text{vertical deflection (divisions)} \times \text{VOLTS/DIV setting}$$

Substituting the given values:

Volts Peak to Peak = 4.6 X 0.5 V

The peak-to-peak voltage is 2.3 volts.

Instantaneous Voltage Measurements—DC

1. Connect the signal to either input connector.

2. Set the VERT MODE switch to display the channel used.

3. Set the VOLTS/DIV switch to display about five divisions of the waveform.

4. Set the Input Coupling switch to GND.

5. Set the A TRIG MODE switch to AUTO.

6. Position the trace to the bottom line of the graticule or other reference line. If the voltage to be measured is negative with respect to ground, position the trace to the top line of the graticule. Do not move the vertical POSITION control after this reference line has been established.

NOTE

To measure a voltage level with respect to a voltage other than ground, make the following changes in step 6: Set the Input Coupling switch to DC and apply the reference voltage to the input connector. Then position the trace to the reference line.

7. Set the Input Coupling switch to DC. The ground reference line can be checked at any time by switching to the GND position.

8. Set the A Trigger controls to obtain a stable display. Set the TIME/DIV switch to a setting that displays several cycles of the signal.

9. Measure the distance in divisions between the reference line and the point on the waveform at which the DC level is to be measured. For example, in Fig. 3 the measurement is made between the reference line and point A.

10. Establish the polarity of the signal. If the waveform is above the reference line, the voltage is positive; below the line, negative (when the INVERT switch is pushed in if using Channel 2).

11. Multiply the distance measured in step 9 by the VOLTS/DIV switch setting. Include the attenuation factor of the probe if using a probe that does not have a scale-factor switching connector.

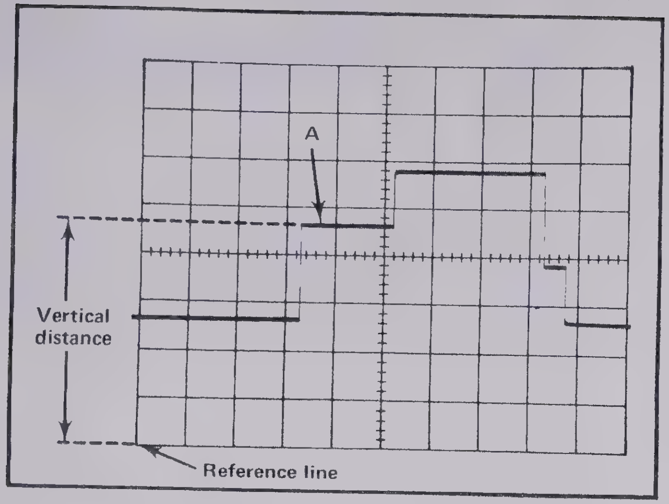


Fig. 3. Measuring instantaneous DC voltage with respect to a reference voltage.

Example. Assume that the vertical distance measured is 4.6 divisions (see Fig. 3), the waveform is above the reference line, and the VOLTS/DIV switch is set to 2.

Using the formula:

$$\text{Instantaneous Voltage} = \text{vertical distance (divisions)} \times \text{polarity} \times \text{VOLTS/DIV setting}$$

Substituting the given values:

$$\text{Instantaneous Voltage} = 4.6 \times +1 \times 2\ \text{V}$$

The instantaneous voltage is +9.2 volts.

Comparison Measurements

In some applications it may be desirable to establish arbitrary units of measurement other than those indicated by the VOLTS/DIV switch or TIME/DIV switch. This is particularly useful when comparing unknown signals to a reference amplitude or repetition rate. One use for the comparison-measurement technique is to facilitate calibration of equipment (e.g., on an assembly-line test) where the desired amplitude or repetition rate does not produce an exact number of divisions of deflection. The adjustment will be easier and more accurate if arbitrary units of measurement are established so that correct adjustment is indicated by an exact number of division of deflection. Arbitrary sweep rates can be useful for comparing harmonic signals to a fundamental frequency, or for comparing the repetition rate of the input and output pulses in a digital count-down circuit. The following procedure describes how to establish arbitrary units of measure for comparison measurements. Although the procedure for establishing vertical and horizontal arbitrary units of measurement is much the same, both processes are described in detail.

Vertical Deflection Factor. To establish an arbitrary vertical deflection factor based upon a specific reference amplitude, proceed as follows:

1. Connect the reference signal to the input connector. Set the TIME/DIV switch to display several cycles of the signal.

2. Set the VOLTS/DIV switch and the VAR VOLTS/DIV control to produce a display an exact number of graticule divisions in amplitude. Do not change the VAR VOLTS/DIV control after obtaining the desired deflection. This display can be used as a reference for amplitude comparison measurements.

3. To establish an arbitrary vertical deflection factor so the amplitude of an unknown signal can be measured accurately at any setting of the VOLTS/DIV switch, the amplitude of the reference signal must be known. If it is not known, it can be measured before the VAR VOLTS/DIV control is set in step 2.

4. Divide the amplitude of the reference signal (volts) by the product of the vertical deflection established in step 2 (divisions) and the setting of the VOLTS/DIV switch. This is the vertical conversion factor.

$$\text{Vertical Conversion Factor} = \frac{\text{reference signal amplitude (volts)}}{\text{vertical deflection (divisions)} \times \text{VOLTS/DIV switch setting}}$$

5. To measure the amplitude of an unknown signal, disconnect the reference signal and connect the unknown signal to the input connector. Set the VOLTS/DIV switch to a setting that provides sufficient vertical deflection to make an accurate measurement. Do not readjust the VAR VOLTS/DIV control.

6. Measure the vertical deflection in divisions and calculate the amplitude of the unknown signal using the following formula.

$$\text{Signal Amplitude} = \text{VOLTS/DIV switch setting} \times \text{vertical conversion factor} \times \text{vertical deflection (divisions)}$$

Example. Assume a reference signal amplitude of 30 volts, a VOLTS/DIV switch setting of 5, and the VAR VOLTS/DIV control is adjusted to provide a vertical deflection of four divisions.

Substituting these values in the vertical conversion factor formula (step 4);

$$\text{Vertical Conversion} = \frac{30\ \text{V}}{4 \times 5\ \text{V}} = 1.5$$

Then with a VOLTS/DIV switch setting of 1, the peak-to-peak amplitude of an unknown signal which produces a vertical deflection of five divisions can be determined by using the signal amplitude formula (step 6):

$$\text{Signal Amplitude} = 1\ \text{V} \times 1.5 \times 5 = 7.5\ \text{volts}$$

Sweep Rates. To establish an arbitrary horizontal sweep rate based upon a specific reference frequency, proceed as follows:

1. Connect the reference signal to the input connector. Set the VOLTS/DIV switch for four or five divisions of vertical deflection.

2. Set the TIME/DIV switch and the VAR TIME/DIV control so one cycle of the signal covers an exact number of horizontal divisions. Do not change the VAR TIME/DIV control after obtaining the desired deflection. This display can be used as a reference for frequency comparison measurements.

3. To establish an arbitrary sweep rate so the repetition rate of an unknown signal can be measured accurately at any setting of the TIME/DIV switch, the repetition rate of the reference signal must be known. If it is not known, it can be measured before the VAR TIME/DIV control is set in step 2.

4. Divide the repetition rate of the reference signal (seconds) by the product of the horizontal deflection established in step 2 (divisions) and the setting of the TIME/DIV switch. This is the horizontal conversion factor:

$$\text{Horizontal Conversion Factor} = \frac{\text{reference signal repetition rate (seconds)}}{\text{horizontal deflection (divisions)} \times \text{TIME/DIV switch setting}}$$

5. To measure the repetition rate of an unknown signal, disconnect the reference signal and connect the unknown signal to the input connector. Set the TIME/DIV switch to a setting that provides sufficient horizontal deflection to make an accurate measurement. Do not readjust the VAR TIME/DIV control.

6. Measure the horizontal deflection in divisions and calculate the repetition rate of the unknown signal using the following formula:

$$\text{Repetition Rate} = \begin{matrix}\text{TIME/DIV} \\ \text{switch} \\ \text{setting}\end{matrix} \times \begin{matrix}\text{horizontal} \\ \text{conversion} \\ \text{factor}\end{matrix} \times \begin{matrix}\text{horizontal} \\ \text{deflection} \\ \text{(divisions)}\end{matrix}$$

NOTE

If the horizontal magnifier is used be sure to use the magnified sweep rate in place of the TIME/DIV switch setting.

Example. Assume a reference signal frequency of 455 hertz (repetition rate 2.19 milliseconds) and a TIME/DIV switch setting of .2 ms, with the VAR TIME/DIV control adjusted to provide a horizontal deflection of eight divisions. Substituting these values in the horizontal conversion factor formula (step 4):

$$\text{Horizontal Conversion Factor} = \frac{2.19 \text{ milliseconds}}{.2 \times 8} = 1.37$$

Then, with a TIME/DIV switch setting of 50 μs the repetition rate of an unknown signal which completes one cycle in seven horizontal divisions can be determined by using the repetition rate formula (step 6):

$$\text{Repetition Rate} = 50\ \mu\text{s} \times 1.37 \times 7 = 480\ \mu\text{s}$$

This answer can be converted to frequency by taking the reciprocal of the repetition rate (see applications on Determining Frequency).

Time-Duration Measurements

1. Connect the signal to either input connector.

2. Set the VERT MODE switch to display the channel used.

3. Set the VOLTS/DIV switch to display about five divisions of the waveform.

4. Set the A Trigger controls to obtain a stable display.

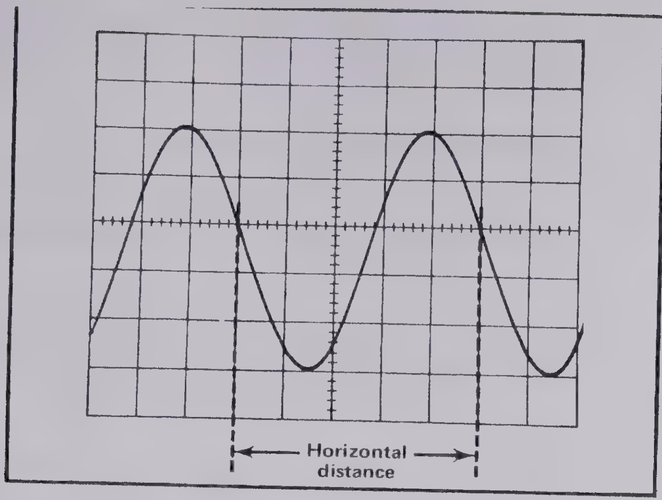


Fig. 4. Measuring the time duration between points on a waveform.

5. Set the TIME/DIV switch to the fastest sweep rate that displays less than ten divisions between the time measurement points (see Fig. 4).

6. Adjust the vertical POSITION control to move the points between which the time measurement is made to the center horizontal line.

7. Adjust the horizontal POSITION control to center the display within the graticule.

8. Measure the horizontal distance between the time measurement points. Be sure the A VAR TIME/DIV control is set to the calibrated detent.

9. Multiply the distance measured in step 8 by the setting of the TIME/DIV switch. If sweep magnification is used, divide this answer by 10.

Example. Assume that the distance between the time measurement points is five divisions (see Fig. 4) and the TIME/DIV switch is set to .1 ms with the magnifier off.

Using the formula:

$$\text{Time Duration} = \frac{\text{horizontal distance (divisions)} \times \text{TIME/DIV setting}}{\text{magnification}}$$

Substitute the given values:

$$\text{Time Duration} = \frac{5 \times 0.1 \text{ ms}}{1}$$

The time duration is 0.5 millisecond.

Frequency Measurement

The time measurement technique can also be used to determine the frequency of a signal. The frequency of a periodically recurrent signal is the reciprocal of the time duration (period) of one cycle.

Use the following procedure:

1. Measure the time duration of one cycle of the waveform as described in the previous application.

2. Take the reciprocal of the time duration to determine the frequency.

Example. The frequency of the signal shown in Fig. 4 which has a time duration of 0.5 millisecond is:

$$\text{Frequency} = \frac{1}{\text{time duration}} = \frac{1}{0.5\ \text{ms}} = 2\ \text{kHz}$$

Risetime Measurements

Risetime measurements employ basically the same techniques as time-duration measurements. The main difference is the points between which the measurement is made. The following procedure gives the basic method of measuring risetime between the 10% and 90% points of the waveform. Falltime can be measured in the same manner on the trailing edge of the waveform.

1. Connect the signal to either input connector.

2. Set the VERT MODE switch to display the channel used.

3. Set the VOLTS/DIV switch and VAR control to produce a display exactly five divisions in amplitude.

4. Center the display about the center horizontal line with the vertical POSITION control.

5. Set the A Trigger controls to obtain a stable display.

6. Set the TIME/DIV switch to the fastest sweep rate that will display less than eight divisions between the 10% and 90% points on the waveform.

7. Adjust the horizontal POSITION control to move the 10% point of the waveform to the second vertical line of the graticule (see Fig. 5).

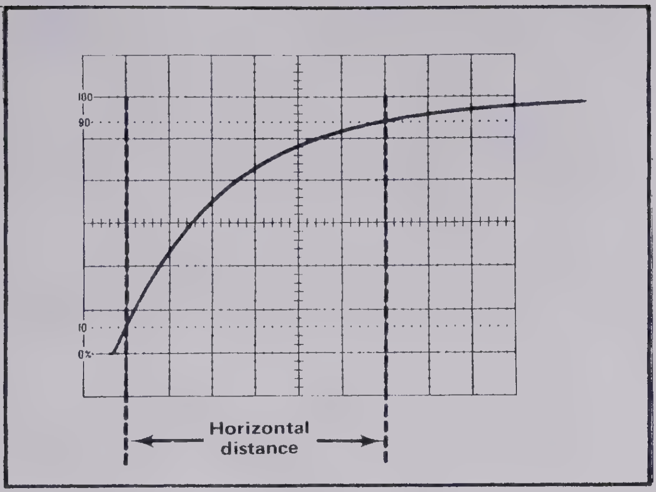


Fig. 5. Measuring risetime.

8. Measure the horizontal distance between the 10% and 90% points. Be sure the VAR TIME/DIV control is set to the calibrated detent.

9. Multiply the distance measured in step 8 by the setting of the TIME/DIV switch.

Example. Assume that the horizontal distance between the 10% and 90% points is six divisions (see Fig. 5) and the TIME/DIV switch is set to 1 μs.

Using the time duration formula to find risetime:

$$\begin{array}{c} \text{Time} \\ \text{Duration} \\ \text{(risetime)} \end{array} = \begin{array}{c} \text{horizontal} \\ \text{distance} \\ \text{(divisions)} \end{array} \times \begin{array}{c} \text{TIME/DIV} \\ \text{setting} \end{array}$$

Substituting the given values:

$$\text{Risetime} = 6 \times 1\ \mu\text{s}$$

The risetime is 6 microseconds.

Time-Difference Measurements

The calibrated sweep rate and dual-trace features of the 465 allow measurement of time difference between two separate events. To measure time difference, use the following procedure:

1. Set the Input Coupling switches to the desired coupling positions.

2. Set the VERT MODE switch to either CHOP or ALT. In general, CHOP is more suitable for low-frequency signals and the ALT position is more suitable for high-frequency signals.

3. Set the A Trigger SOURCE switch to CH 1.

4. Connect the reference signal to the CH 1 OR X connector and the comparison signal to the CH 2 OR Y connector. The reference signal should precede the comparison signal in time. Use coaxial cables or probes which have equal time delay to connect the signals to the input connectors.

5. If the signals are of opposite polarity, push the INVERT pushbutton to invert the Channel 2 display (signals may be of opposite polarity due to 180° phase difference; if so, take this into account in the final calculation).

6. Set the VOLTS/DIV switches to produce four- or five-division displays.

7. Set the A LEVEL control for a stable display.

8. If possible, set the TIME/DIV switch for a sweep rate which shows three or more divisions between the two waveforms.

9. Adjust the vertical POSITION controls to center each waveform (or the points on the display between which the measurement is made) in relation to the center horizontal line.

10. Adjust the horizontal POSITION control so the Channel 1 (reference) waveform crosses the center horizontal line at a vertical graticule line.

11. Measure the horizontal difference between the Channel 1 waveform and the Channel 2 waveform (see Fig. 6).

12. Multiply the measured difference by the setting of the TIME/DIV switch. If sweep magnification is used, divide this answer by 10.

Example. Assume that the TIME/DIV switch is set to 50 μs, the MAG switch to X10 and the horizontal difference between waveforms is 4.5 divisions (see Fig. 6).

Using the formula:

$$\text{Time Delay} = \frac{\begin{matrix}\text{TIME/DIV} \\ \text{setting}\end{matrix} \quad \text{X} \quad \begin{matrix}\text{horizontal} \\ \text{difference} \\ \text{(divisions)}\end{matrix}}{\text{magnification}}$$

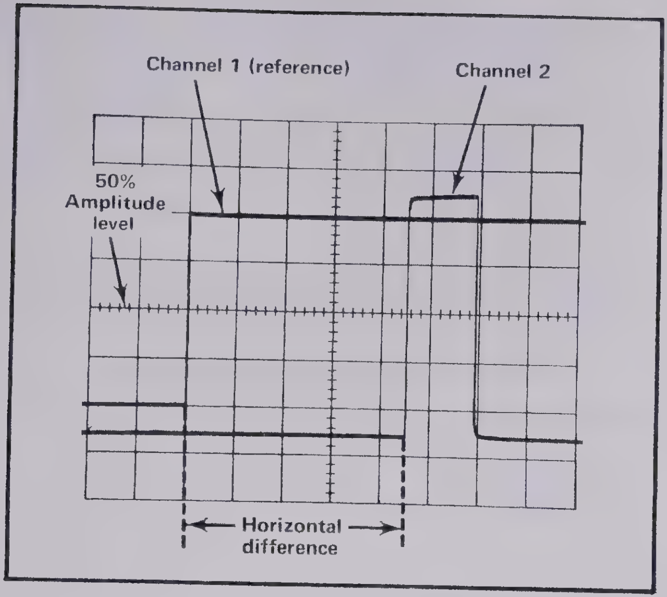


Fig. 6. Measuring time difference between two pulses.

Substituting the given values:

$$\text{Time Delay} = \frac{50\ \mu s \times 4.5}{10}$$

The time delay is 22.5 microseconds.

Delayed or Mixed Sweep Time Measurement

The delayed sweep mode can be used to make accurate time measurements. The following measurement determines the time difference between two pulses displayed on the same trace. This application may also be used to measure time difference from two different sources (dual-trace) or to measure time duration of a single pulse.

1. Connect the signal to either input connector. Set the VERT MODE switch to display the channel used.

2. Set the VOLTS/DIV switch to produce a display about four divisions in amplitude.

3. If possible, set the A TIME/DIV switch to a sweep rate which displays about eight divisions between the pulses.

4. Adjust the A Trigger controls for a stable display.

5. Set the HORIZ DISPLAY switch to A INT and the B Trigger SOURCE switch to STARTS AFTER DELAY.

6. Set the B TIME/DIV switch to a setting 1/1000th of the A TIME/DIV sweep rate. This produces an intensified portion about 0.1 division in length.

7. Turn the DELAY-TIME POSITION dial to move the intensified portion to the first pulse.

8. Set the HORIZ DISPLAY switch to B DLY'D.

9. Adjust the DELAY-TIME POSITION dial to move the pulse (or the rising portion) to some vertical reference line. Note the setting of the DELAY-TIME POSITION dial.

10. Turn the DELAY-TIME POSITION dial clockwise until the second pulse is positioned to this same point (if several pulses are displayed, return to the A INT position to locate the correct pulse). Again note the dial setting.

11. Subtract the first dial setting from the second and multiply the difference by the delay time shown by the A TIME/DIV switch. This is the time interval between the pulses.

12. If the MIX mode of operation is used, the same general procedure can be used to determine sweep time. With the first part of the display at a slower sweep rate set by the A TIME/DIV switch, it will not be necessary to switch display modes to insure location of the correct pulse. However, because of inaccuracies that would be introduced into the measurement, a fixed graticule reference point cannot be used in the MIX mode in the manner normally recommended for making differential time measurements. The B DLY'D mode is considered the most accurate and therefore the recommended mode of making differential time measurements.

Example. Assume the first dial setting is 1.31 and the second dial setting is 8.81 with the A TIME/DIV switch set to 0.2 μs (see Fig. 7).

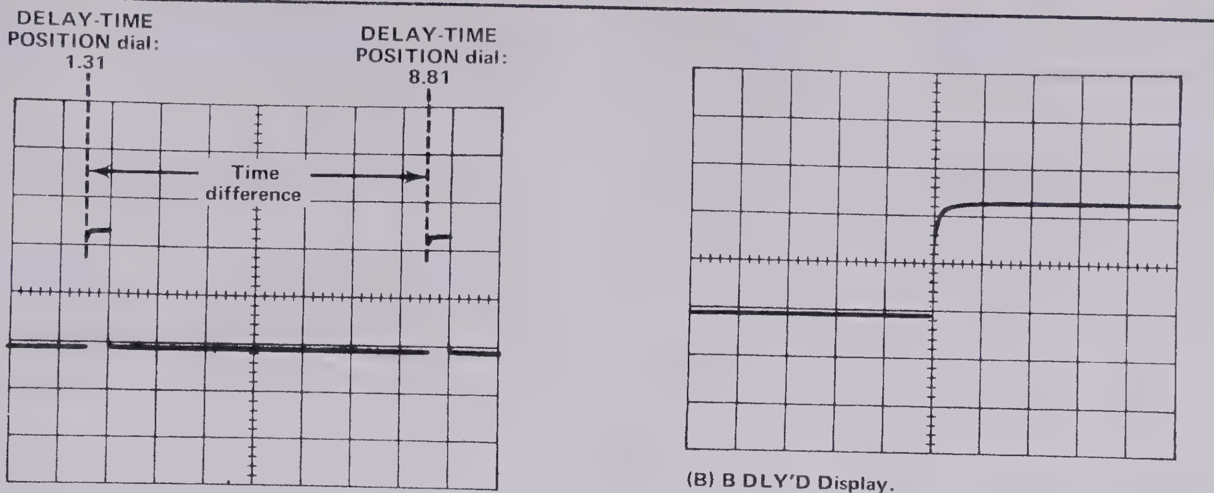
Using the formula:

$$\text{Time Difference (delayed sweep)} = \left[\text{second dial setting} - \text{first dial setting}\right] \times \begin{array}{c}\text{delay time}\\ \text{(A TIME/DIV}\\ \text{setting)}\end{array}$$

Substituting the given values:

Time Difference = $(8.81 - 1.31) \times 0.2\ \mu s$.

The time difference is 1.5 microseconds.



(A) A Display.

(B) B DLY'D Display.

Fig. 7. Measuring time difference using delayed sweep.

Delayed or Mixed Sweep Magnification

The delayed sweep features of the 465 can be used to provide higher apparent magnification than is provided by the X10 MAG switch. The sweep rate of the delayed sweep (B sweep) is not actually increased; the apparent magnification is the result of delaying the B sweep an amount of time selected by the A TIME/DIV switch and the DELAY-TIME POSITION dial before the display is presented at the sweep rate selected by the B TIME/DIV switch. The following method uses the STARTS AFTER DELAY position of the B Trigger SOURCE switch to allow the delayed portion to be positioned with the DELAY-TIME POSITION dial. If there is too much jitter in the delayed display, use the Triggered B Sweep mode of operation.

1. Connect the signal to either input connector. Set the VERT MODE switch to display the channel used.

2. Set the VOLTS/DIV switch to produce a display about four divisions in amplitude.

3. Set the A TIME/DIV switch to a sweep rate which displays the complete waveform.

4. Adjust the A Trigger controls for a stable display.

5. Set the HORIZ DISPLAY switch to A INT and the B Trigger SOURCE switch to STARTS AFTER DELAY.

6. Position the start of the intensified portion with the DELAY-TIME POSITION dial to the part of the display to be magnified.

7. Set the B TIME/DIV switch to a setting which intensifies the full portion to be magnified. The start of the intensified trace remains as positioned above.

8. Set the HORIZ DISPLAY switch to B DLY'D.

9. Time measurements can be made from the display in the conventional manner. Sweep rate is determined by the setting of the B TIME/DIV switch.

10. Set the HORIZ DISPLAY switch to MIX.

11. Time measurements can be made from the display in the conventional manner. Sweep rate of the first part of the display is determined by the setting of the A TIME/DIV switch and the sweep rate of the latter part of the display is determined by the setting of the B TIME/DIV switch.

12. The apparent sweep magnification can be calculated by dividing the A TIME/DIV switch setting by the B TIME/DIV switch setting.

Example. The apparent magnification of a display with an A TIME/DIV switch setting of .1 ms and a B TIME/DIV switch setting of 1 μs is:

$$\text{Apparent Magnification (Delayed Sweep} = \frac{\text{A TIME/DIV setting}}{\text{B TIME/DIV setting}}$$

Substituting the given values:

$$\text{Apparent Magnification} = \frac{1 \times 10^{-4}}{1 \times 10^{-6}}$$

The apparent magnification is 100 times.

Triggered Delay Sweep Magnification. The delayed sweep magnification method just described may produce too much jitter at high apparent magnification ranges. Operating the B Sweep in a triggered mode provides a more stable display since the delayed display is triggered at the same point each time.

1. Set up the display as given in steps 1 through 7 described above.

2. Set the B Trigger SOURCE switch to the same position as the A Trigger SOURCE switch.

3. Adjust the B LEVEL control so the intensified portion on the trace is stable. (If an intensified portion cannot be obtained, see step 4.)

4. Inability to intensify the desired portion indicates that the signal does not meet the triggering requirements. If the condition cannot be remedied with the B Triggering controls or by increasing the display amplitude (lower VOLTS/DIV setting), trigger B Sweep externally.

5. When the correct portion is intensified, set the HORIZ DISPLAY switch to B DLY'D. Slight readjustment of the B LEVEL control may be necessary for a stable display.

6. Measurement and magnification are as described above.

Pulse Jitter Measurements

In some applications it is necessary to measure the amount of jitter on the leading edge of a pulse or jitter between pulses.

Use the following procedure:

1. Connect the signal to either input connector. Set the VERT MODE switch to display the channel used.

2. Set the VOLTS/DIV switch to display about four divisions of the waveform.

3. Set the A TIME/DIV switch to a sweep rate which displays the complete waveform.

4. Set the A Trigger controls to obtain as stable a display as possible.

5. Set the HORIZ DISPLAY switch to A INT and the B Trigger SOURCE switch to STARTS AFTER DELAY.

6. Position the start of the intensified portion with the DELAY-TIME POSITION dial so the pulse to be measured is intensified.

7. Set the B TIME/DIV switch to a setting that intensifies the full portion of the pulse which shows jitter.

8. Set the HORIZ DISPLAY switch to B DLY'D.

9. Pulse jitter is shown by horizontal movement of the pulse (take into account inherent jitter of Delayed Sweep). Measure the amount of horizontal movement. Be sure the VAR TIME/DIV control is set to the calibrated detent.

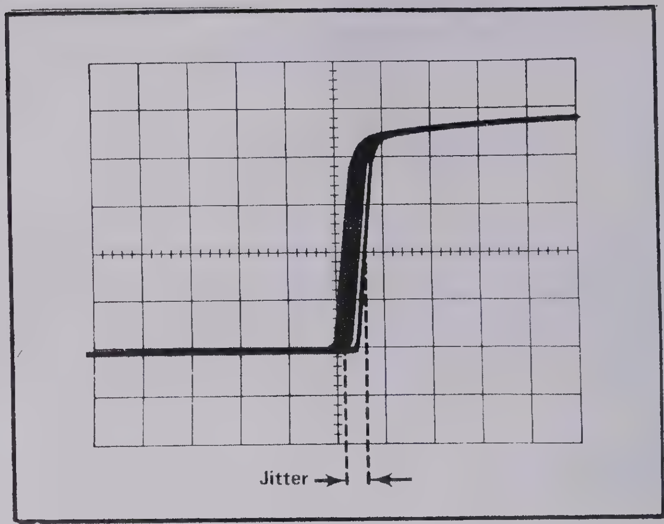


Fig. 8. Measuring pulse jitter.

10. Multiply the distance measured in step 9 by the B TIME/DIV switch setting to obtain pulse jitter in time.

Example. Assume that the horizontal movement is 0.5 division (see Fig. 8), and the B TIME/DIV switch setting is 0.5 μs.

Using the formula:

$$\text{Pulse Jitter} = \begin{matrix}\text{horizontal}\\ \text{jitter}\\ \text{(divisions)}\end{matrix} \times \begin{matrix}\text{B TIME/DIV}\\ \text{setting}\end{matrix}$$

Substituting the given values:

Pulse Jitter = 0.5 X 0.5 μs

The pulse jitter is 0.25 microsecond.

Delayed Trigger Generator

The B + GATE output signal can be used to trigger an external device at a selected delay time after the start of A Sweep. The delay time of the B + GATE output signal can be selected by the setting of the DELAY-TIME POSITION dial and A TIME/DIV switch.

A Sweep Triggered Internally. When A Sweep is triggered internally to produce a normal display, the delayed trigger may be obtained as follows:

1. Obtain a triggered display in the normal manner.

2. Set the HORIZ DISPLAY switch to A INT.

3. Select the amount of delay from the start of A Sweep with the DELAY-TIME POSITION dial. Delay time can be calculated in the normal manner.

4. Set the B Trigger SOURCE switch to STARTS AFTER DELAY.

5. Connect the B + GATE signal to the external equipment.

6. The duration of the B + GATE signal is determined by the setting of the B TIME/DIV switch.

7. The external equipment will be triggered at the start of the intensified portion if it responds to positive-going triggers, or at the end of the intensified portion if it responds to negative-going triggers.

A Sweep Triggered Externally. This mode of operation can be used to produce a delayed trigger with or without a corresponding display. Connect the external trigger signal to the A external trigger input connector and set the A SOURCE switch to EXT. Follow the operation given above to obtain the delayed trigger.

Normal Trigger Generator

Ordinarily, the signal to be displayed also provides the trigger signal for the oscilloscope. In some instances, it may be desirable to reverse this situation and have the oscilloscope trigger the signal source. This can be done by connecting the A + GATE signal to the input of the signal source. Set the A LEVEL control fully clockwise. A TRIG MODE switch to AUTO and adjust the A TIME/DIV switch for the desired display. Since the signal source is triggered by a signal that has a fixed time relationship to the sweep, the output of the signal source can be displayed on the CRT as though the 465 were triggered in the normal manner.

Multi-Trace Phase Difference Measurements

Phase comparison between two signals of the same frequency can be made using the dual-trace feature of the 465. This method of phase difference measurement can be used up to the frequency limit of the vertical system. To make the comparison, use the following procedure:

1. Set the Input Coupling switches to the same position, depending on the type of coupling desired.

2. Set the VERT MODE switch to either CHOP or ALT. In general, CHOP is more suitable for low-frequency signals and the ALT position is more suitable for high-frequency signals.

3. Set the A Trigger SOURCE switch to CH 1.

4. Connect the reference signal to the CH 1 OR X input connector and the comparison signal to the CH 2 OR Y input connector. The reference signal should precede the comparison signal in time. Use coaxial cables or probes which have equal time delay to connect the signals to the input connectors.

5. If the signals are of opposite polarity, set the INVERT pushbutton in to invert the Channel 2 display. (Signals may be of opposite polarity due to 180° phase difference; if so, take this into account in the final calculation.)

6. Set the CH 1 and CH 2 VOLTS/DIV switches and the CH 1 and CH 2 VAR controls so the displays are equal and about five divisions in amplitude.

7. Set the A Trigger controls to obtain a stable display.

8. Set the A TIME/DIV switch to a sweep rate which displays about one cycle of the waveform.

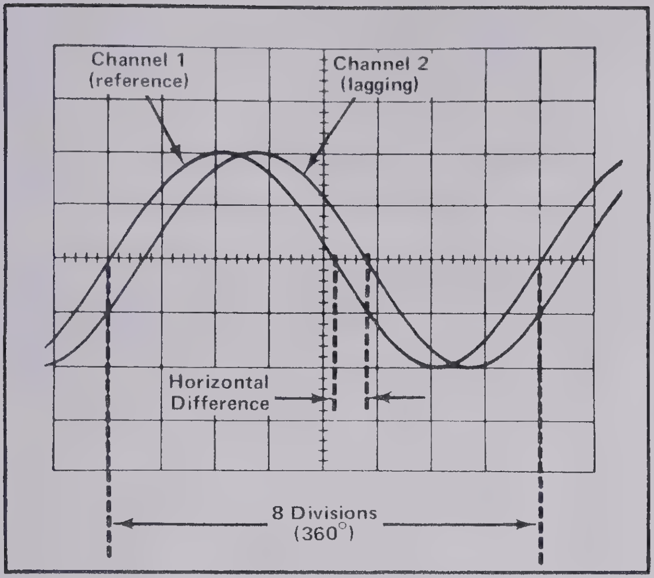


Fig. 9. Measuring phase difference.

9. Move the waveforms to the center of the graticule with the CH 1 and CH 2 POSITION controls.

10. Turn the A VAR TIME/DIV control until one cycle of the reference signal (Channel 1) occupies exactly eight divisions between the first and ninth graticule lines (see Fig. 9). Each division of the graticule represents 45° of the cycle (360° ÷ 8 divisions = 45°/division). The sweep rate can be stated in terms of degrees as 45°/division.

11. Measure the horizontal difference between corresponding points on the waveforms.

12. Multiply the measured distance (in divisions) by 45°/division (sweep rate) to obtain the exact amount of phase difference.

Example. Assume a horizontal difference of 0.6 division with a sweep rate of 45°/division as shown in Fig. 9.

Using the formula:

$$\text{Phase Difference} = \begin{array}{c}\text{horizontal}\\ \text{difference}\\ \text{(divisions)}\end{array} \times \begin{array}{c}\text{sweep rate}\\ \text{(degrees/div)}\end{array}$$

Substituting the given values:

$$\text{Phase Difference} = 0.6 \times 45^\circ$$

The phase difference is 27°.

High Resolution Phase Measurements

More accurate dual-trace phase measurements can be made by increasing the sweep rate (without changing the A VAR TIME/DIV control setting). One of the easiest ways to increase the sweep rate is with the X10 MAG switch. Delayed sweep magnification may also be used. The magnified sweep rate is determined by dividing the sweep rate obtained previously by the amount of sweep magnification.

Example. If the sweep rate were increased 10 times with the magnifier, the magnified sweep rate would be $45^\circ \div 10 = 4.5^\circ$/division. Fig. 10 shows the same signals as used in Fig. 9 but with the X10 MAG switch set to X10. With a horizontal difference of 6 divisions, the phase difference is:

$$\text{Phase Difference} = \begin{matrix}\text{horizontal}\\ \text{difference}\\ \text{(divisions)}\end{matrix} \times \begin{matrix}\text{magnified sweep rate}\\ \text{(degrees/div)}\end{matrix}$$

Substituting the given values:

Phase Difference = $6 \times 4.5^\circ$.

The phase difference is 27°.

X-Y Phase Measurement

The X-Y phase measurement method can be used to measure the phase difference between two signals of the same frequency. This method provides an alternate method of measurement for signal frequencies up to 50 kilohertz.

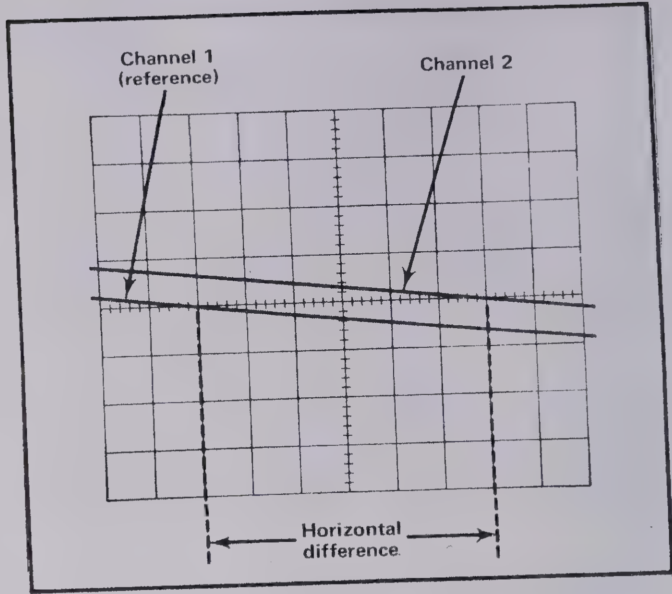


Fig. 10. High-resolution phase-difference measurement with increased sweep rate.

However, above this frequency the inherent phase difference between the vertical and horizontal system makes accurate phase measurement difficult. In this mode, one of the sinewave signals provides horizontal deflection (X) while the other signal provides the vertical deflection (Y). The phase angle between the two signals can be determined from the lissajous pattern as follows:

1. Connect one of the sine-wave signals to the CH 1 OR X input connector and the other signal to the CH 2 OR Y input.

2. Set the TIME/DIV switch to X-Y and the X10 MAG switch to off.

3. Position the display to the center of the screen and adjust the CH 1 and CH 2 VOLTS/DIV switches to produce a display less than eight divisions vertically (Y) and less than 10 divisions horizontally (X). The CH 1 VOLTS/DIV switch controls the horizontal deflection (X) and the CH 2 VOLTS/DIV switch controls the vertical deflection (Y).

4. Center the display in relation to the center graticule lines. Measure the distance A and B as shown in Fig. 11. Distance A is the horizontal measurement between the two points where the trace crosses the center horizontal line. Distance B is the maximum horizontal width of the display.

5. Divide A by B to obtain the sine of the phase angle (Φ) between the two signals. The angle can then be obtained from a trigonometric table.

6. If the display appears as a diagonal straight line, the two signals are either in phase (tilted upper right to lower left) or 180° out of phase (tilted upper left to lower right). If the display is a circle, the signals are 90° out of phase.

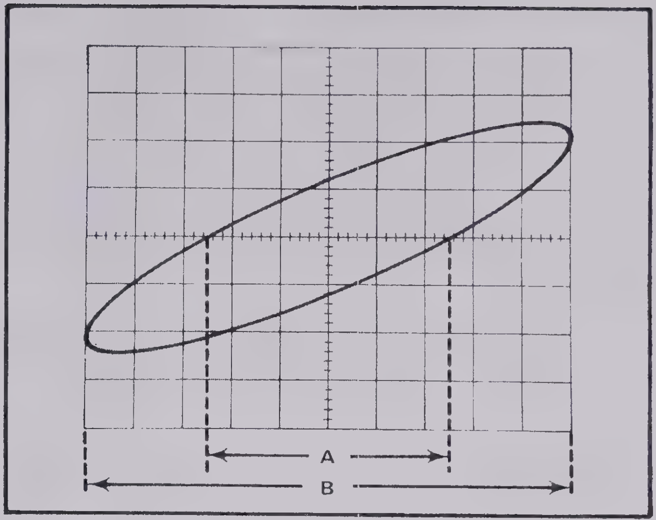


Fig. 11. Phase-difference measurement from an X-Y display.

Example. To measure the phase of the display shown in Fig. 11 where A is 5 divisions and B is 10 divisions, use the formula:

$$\text{Sine } \Phi = \frac{A}{B}$$

Substituting the given values:

$$\text{Sine } \Phi = \frac{5}{10} = 0.5$$

From the trigonometric tables:

$$\Phi = 30^\circ$$

Common-Mode Rejection

The ADD feature of the 465 can be used to display signals which contain undersirable components. These undersirable components can be eliminated through common-mode rejection. The precautions given under Algebraic Addition should be observed.

1. Connect the signal containing both the desired and undesired information to the CH 1 OR X connector.

2. Connect a signal similar to the unwanted portion of the Channel 1 signal to the CH 2 OR Y connector.

3. Set both Input Coupling switches to DC (AC if DC component of input signal is too large).

4. Set the VERT MODE switch to ALT. Set the VOLTS/DIV switches so the signals are about equal in amplitude.

5. Set the A Trigger SOURCE switch to NORM.

6. Set the VERT MODE switch to ADD. Push in the INVERT switch so the common-mode signals are of opposite polarity.

7. Adjust the CH 2 VOLTS/DIV switch and CH 2 VAR control for maximum cancellation of the common-mode signal.

8. The signal which remains should be only the desired portion of the Channel 1 signal. The undesired signal is cancelled out.

Example. An example of this mode of operation is shown in Fig. 12. The signal applied to Channel 1 contains unwanted line-frequency components (see Fig. 12A). A corresponding line-frequency signal is connected to Channel 2 (see Fig. 12B). Fig. 12C shows the desired portion of the signal as displayed when common-mode rejection is used.

OPERATIONAL FEATURES

General

The TEKTRONIX 465 Oscilloscope is a dual-channel, 100 megahertz portable instrument using only solid state and integrated circuit components (except the CRT). The relatively small size and light weight of the 465 allow it to be easily transported and yet still be capable of performance necessary for accurate high-frequency measurements. The dual-channel DC-to-100 MHz vertical system provides

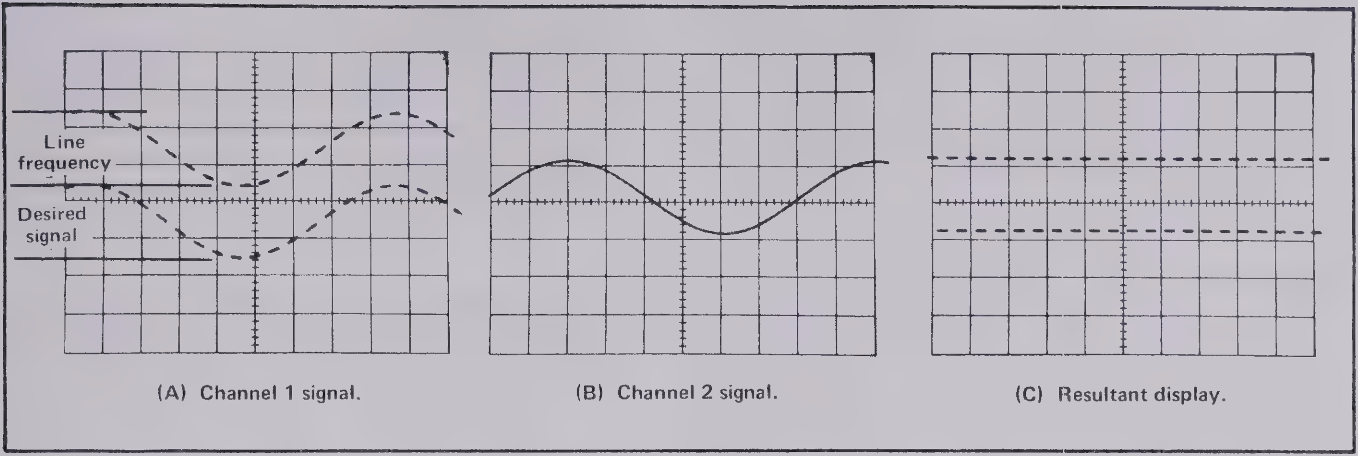


Fig. 12. Using the ADD feature for common-mode rejection. (A) Channel 1 signal contains desired information along with line-frequency component. (B) Channel 2 signal contains line-frequency only. (C) CRT display using common-mode rejection.

calibrated deflection factors from 5 millivolts to 5 volts/division. The sweep trigger circuits are capable of stable triggering over the full bandwidth capabilities of the vertical deflection system. The horizontal deflection system provides calibrated sweep rates from 0.5 seconds to 0.05 microsecond/division along with delayed sweep features for accurate relative-time measurements. The regulated DC power supplies maintain constant output over a wide variation of line voltages and frequencies. Total maximum power consumption of the instrument is approximately 75 watts.

Intensity Control

The INTENSITY control determines the brightness of the display presented on the CRT. Since the brightness of the CRT display affects the amount of current drained from the batteries, the INTENSITY control should be set to the minimum level that provides a usable display. This will allow the maximum operating time when operating on the optional external battery supply. The setting of the INTENSITY control may affect the correct focus of the display. Slight re-adjustment of the FOCUS may be

necessary when the intensity level is changed. To protect the CRT phosphor, do not turn the INTENSITY control higher than necessary to provide a satisfactory display. Be careful that the INTENSITY control is not set too high when changing the TIME/DIV switches from fast to slow sweep rates, or when changing to the X-Y mode of operation.

Graticule

The graticule of the 465 is internally marked on the face-plate of the CRT to provide accurate, no-parallax measurements. The graticule is marked with eight vertical and ten horizontal divisions. Each major division is segmented into five minor divisions at the center vertical and horizontal lines. The vertical gain and horizontal timing are calibrated to the graticule so accurate measurements can be made from the CRT display directly.

Vertical Mode of Operation

Single-Trace Displays. Either of the input channels can be used for single-trace displays. Apply the signal to the desired input connector and set the VERT MODE switch to display the channel used. The trigger SOURCE switches can select either vertical channel as a trigger signal source; however, only Channel 2 has the INVERT function so the correct channel must be selected to take advantage of this feature.

Dual-Trace Operation (Alternate Mode). The ALT position of the VERT MODE switch produces a display which alternates between Channel 1 and Channel 2 with each sweep of the CRT. Although the ALT mode can be used at all sweep rates, the CHOP mode provides a more satisfactory display at sweep rates below about 50 microseconds/division. At these slower sweep rates, alternate mode switching becomes visually perceptible.

When triggering in the NORM position of the trigger SOURCE switches, the sweep is triggered from the signal on each channel. This provides a stable display of two unrelated signals, but does not indicate the time relationship between the signals. In the CH 1 or CH 2 positions of the trigger SOURCE switches, the two signals will be displayed showing true time relationship. If the signals are not time related, one of the signals displayed will be unstable.

Dual-Trace Operation (Chopped Mode). The CHOP position of the VERT MODE switch produces a display which is electronically switched between channels. In general, the CHOP mode provides the best display at sweep rates slower than about 50 microseconds/division or whenever dual-trace, single-shot phenomena are to be displayed. At faster sweep rates the chopped switching becomes apparent and may interfere with the display.

Proper internal triggering for the chopped mode of operation cannot be obtained in the NORM position of the trigger SOURCE switches. If the NORM position is used, the sweep circuits are triggered from the between-channel switching signal and both waveforms will be unstable. External triggering from a signal which is time-related to either signal provides the same result as triggering internally from Channel 1 or Channel 2.

Two signals which are time-related can be displayed in the chopped mode showing true time relationship. However, if the signals are not time-related, one signal displayed will appear unstable.

Two single-shot, transient, or random signals which occur within the time interval determined by the TIME/DIV switch (ten times the displayed rate) can be compared using the chopped mode. To obtain a usable display, the sweep must be triggered from the vertical channel displaying the event that occurs first. Since the signals show true time relationship, time difference measurements can be made.

Algebraic Addition. The ADD position of the VERT MODE switch can be used to display the sum or difference of two signals, for common-mode rejection to remove an undesired signal, or for DC offset (applying a DC voltage to one channel to offset the DC component of a signal on the other channel).

The overall deflection factor in the ADD mode when both VOLTS/DIV switches are set to the same position is the same as the deflection factor indicated by either VOLTS/DIV switch. The amplitude of an added mode display can be determined directly from the resultant CRT deflection multiplied by the deflection factor indicated by either VOLTS/DIV switch. However, if the CH 1 and CH 2 VOLTS/DIV switches are set to different deflection factors, the resultant deflection factor is difficult to determine from the CRT display. In this case, the voltage amplitude of the resultant display can be determined accurately only if the amplitude of the signal applied to either channel is known.

The following general precautions should be observed when using the ADD mode.

1. Do not exceed the input voltage rating of the 465.

2. Do not apply signals that exceed an equivalent of about eight times the VOLTS/DIV switch setting. For example, with a VOLTS/DIV switch setting of 0.5, the voltage applied to that channel should not exceed about four volts. Larger voltages may distort the display.

3. Use CH 1 and CH 2 POSITION control settings which most nearly position the signal of each channel to mid-screen when viewed in either the CH 1 or CH 2 positions of the VERT MODE switch. This insures the greatest dynamic range for ADD mode operation.

4. For similar response from each channel, set the CH 1 and CH 2 Input Coupling switches to the same position.

Deflection Factor

The amount of vertical deflection produced by a signal is determined by the signal amplitude, the setting of the VOLTS/DIV switches, and the setting of the VOLTS/DIV VAR controls. The calibrated deflection factors indicated by the VOLTS/DIV switches apply only when the VOLTS/DIV VAR controls are set to the calibrated position (detent fully clockwise).

The VOLTS/DIV VAR controls provide continuously variable (uncalibrated) vertical deflection factors between the calibrated settings of the VOLTS/DIV switches. The VOLTS/DIV VAR controls extend the maximum vertical deflection factor of the 465 to at least 12.5 volts per division (5 volts position).

Ground Considerations

Reliable signal measurements cannot be made unless both the oscilloscope and the unit under test are connected together by a common reference (ground) lead in addition to the signal lead or probe. The ground strap on the signal probe provides the best ground. Also, a ground lead can be connected to the 465 chassis ground banana jack to establish a common ground with the signal source.

Input Coupling

The Input Coupling switches allow a choice of coupling method for the applied signal. The type of display desired and the applied signal determines the coupling method to use.

In the AC coupling position, the DC component of the signal is blocked by a capacitor in the input circuit. The low-frequency −3 dB point in the AC position is about 10 hertz. Therefore, some low-frequency attenuation can be expected near this frequency limit. Attenuation in the form of waveform tilt will also appear in square waves which have low-frequency components. The AC coupling position provides the best display of signals with a DC component which is much larger than the AC component.

The DC coupling position can be used for most applications. This position allows measurement of the DC component of a signal and must be used to display signals below about 20 hertz to avoid the attenuation that would occur using AC coupling.

The GND position provides a ground reference at the input of the 465 without the need to externally ground the probe. The signal applied to the probe is internally disconnected from the input circuit and connected to ground through a one-megohm resistor. The amplifier input circuit is held at ground potential.

In the GND position, connecting the input signal to ground through a one-megohm resistor forms a pre-charging network. This network allows the Input Coupling capacitor to charge to the average DC voltage level of the signal applied to the probe. Since this takes place in the GND position of the Input Coupling switch, any large voltage transients accidently generated will not be applied to the amplifier input. The pre-charge network also provides a measure of protection to the external circuitry by reducing the current levels that can be drawn from the external circuitry during capacitor charging. The following procedure should be used whenever the probe tip is connected to a signal source having a different DC level than that previously applied.

1. Before connecting the probe tip to a signal source, set the Input Coupling to GND.

2. Touch the probe tip to oscilloscope chassis ground. Wait several seconds for the Input Coupling capacitors to discharge.

3. Connect the probe tip to the signal source.

4. Wait several seconds for the Input Coupling capacitor to charge.

5. Set the Input Coupling to AC. The display will remain on screen so the AC component of the signal can be measured in the normal manner.

Trigger Source

Internal Triggering. For most applications the sweep can be triggered internally. In the NORM CH 1, and CH 2 positions of the trigger SOURCE switches, the trigger signal is obtained from the vertical deflection system. For single-trace displays of either channel the NORM position provides the most convenient operation. However, for dual-trace displays, special considerations must be made to provide the correct display. Refer to the Dual-Trace

Operation explanation in the Vertical Mode of Operation portion of the General Operating Instructions for dual-trace triggering information.

Line Triggering. The A Trigger SOURCE switch has a LINE position that the B Trigger SOURCE switch does not have. The LINE position connects a sample of the power-line voltage to the input of the A Trigger Generator. Line triggering is useful when the input signal is time-related (multiple or sub-multiple) to the line frequency. It is also useful for providing a stable display of a line-frequency component in a complex waveform.

External Triggering. An external signal connected to the external trigger input connector can be used to trigger the sweep in the EXT and EXT ÷ 10 positions of the SOURCE switches. The external signal must be time-related to the displayed signal for a stable display. An external trigger signal can be used to provide a triggered display when the internal signal is too low in amplitude for correct triggering, or contains signal components on which it is not desired to trigger. It is also useful when signal tracing in amplifiers, phase-shift networks, wave-shaping circuits, etc. The signal from a single point in the circuit under test can be connected to the external trigger input connector through a cable or signal probe. The sweep is then triggered by the same signal at all times and allows amplitude, time relationship, or waveshape changes of signals at various points in the circuit to be examined without resetting the trigger controls.

B Starts After Delay Time. In the STARTS AFTER DELAY position of the B SOURCE switch, the B Sweep is triggered to run immediately after the delay time. The setting of the DELAY-TIME POSITION control determines the amount of delay time after the start of A Sweep. Since the amount of delay time is the same for each sweep, B Sweep will start at the same point each time and the display appears stable.

Trigger Coupling

Four methods of coupling the trigger signal to the trigger circuits can be selected with the trigger COUPLING switches. Each position permits selection or rejection of certain frequency components of the trigger signal to obtain selective triggering.

AC Coupling. The AC position blocks the DC component of the trigger signal. Signals with low-frequency components below about 30 hertz are attenuated. In general, AC coupling can be used for most applications. However, if the trigger signal contains unwanted frequency components or if the sweep is to be triggered at a low repetition rate or a DC level, one of the remaining COUPLING switch positions will provide a better display.

Low-Frequency Reject. The LF REJ position passes all high-frequency signals above about 15 kilohertz. DC is rejected and signals below about 15 kilohertz are attenuated. When triggering from complex waveforms, this position is useful for providing stable display of the high-frequency components.

High-Frequency Rejection. The HF REJ position passes all low-frequency signals between about 60 hertz and 50 kilohertz. DC is rejected and signals outside the above range are attenuated. When triggering from complex waveforms, this position is useful for providing stable display of the low-frequency components.

DC Coupling. DC coupling can be used to provide stable triggering with low-frequency signals which would be attenuated in the other positions, or with low-repetition rate signals. The LEVEL control can be adjusted to provide triggering at the desired DC level on the waveform. When triggering in the NORM position of the SOURCE switch, the setting of the CH 1 and CH 2 POSITION controls affect the DC triggering level.

DC trigger coupling should not be used in the ALT dual-trace mode if the trigger SOURCE switch is set to NORM. If used, the sweep will trigger on the DC level of one trace and then either lock out completely or free run on the other trace. Correct DC triggering for this mode can be obtained only with the trigger SOURCE switch set to some position other than NORM.

Trigger Slope

The trigger SLOPE switch determines whether the trigger circuit responds on the positive-going or negative-going portion of the trigger signal. When the SLOPE switch is in the + (positive-going) position, the display starts with the positive-going portion of the waveform; in the – (negative-going) position, the display starts with the negative-going portion of the waveform. When several cycles of a signal appear in the display, the setting of the SLOPE switch is often unimportant. However, if only a certain portion of a cycle is to be displayed, correct setting of the SLOPE switch is important to provide a dispaly which starts on the desired slope of the input signal.

Trigger Level

The trigger LEVEL control determines the voltage level on the triggering waveform at which the sweep is triggered. When the LEVEL control is set in the + region, the trigger circuit responds at a more positive point on the trigger signal. When the LEVEL control is set in the – region, the trigger circuit responds at a more negative point on the trigger signal. To set the LEVEL control, first select the

trigger SOURCE, COUPLING, and SLOPE. Then set the LEVEL control fully clockwise and rotate it counterclockwise until the display starts at the desired point.

A Sweep Triggered Light

The A Sweep TRIG light provides a convenient indication of the condition of the A Trigger circuit. If the A Trigger controls are correctly adjusted with an adequate trigger signal applied, this light is on. However, if the A LEVEL control is misadjusted, the A COUPLING or A SOURCE switches incorrectly set, or the trigger signal too low in amplitude, the A Sweep TRIG light will be off. This feature can be used as a general indication of correct triggering. It is particularly useful when setting up the trigger circuits when a trigger signal is available without a trace display on the CRT. It also indicates that the A Sweep is correctly triggered when operating in the B (delayed) Sweep mode.

A Trigger Mode

Automatic Triggering. The AUTO position of the A TRIG MODE switch provides a stable display when the A LEVEL control is correctly set (see Trigger Level portion of General Operating Information) and an adequate trigger signal is present. The A Sweep TRIG light indicates when the A Sweep Generator is triggered.

When the trigger repetition rate is less than about 20 hertz or in the absence of an adequate trigger signal, the A Sweep Generator free runs to produce a reference trace. When an adequate trigger signal is again applied, the free-running condition ends and the A Sweep Generator is triggered to produce a stable display (with the correct LEVEL control setting).

Normal Triggering. Operation in the NORM position of the A TRIG MODE switch is the same as in the AUTO position when a trigger signal is applied. However, when a trigger signal is not present, the A Sweep Generator remains off and there is no display. The A Sweep TRIG light indicates when the A Sweep Generator is triggered.

Use the NORM mode to display signals with repetition rates below about 20 hertz. This mode provides an indication of an adequate trigger signal as well as the correctness of trigger control settings, since there is no display without proper triggering. Also, the A Sweep TRIG light is off when the A Sweep is not correctly triggered.

Single Sweep. When the signal to be displayed is not repetitive or varies in amplitude, shape, or time, a conventional display may produce an unstable presentation. To avoid this, use the single-sweep feature of the 465. The

single-sweep mode can also be used to photograph a non-repetitive signal.

To use the single-sweep mode, first make sure the trigger circuit will respond to the event to be displayed. Set the A TRIG MODE switch to AUTO or NORM and obtain the best possible display in the normal manner (for random signals set the trigger circuit to trigger on a signal which is approximately the same amplitude and frequency as the random signal). Then, set the A TRIG MODE switch to SING SWP and press the PUSH TO RESET button. When the PUSH TO RESET button is pushed, the next trigger pulse will initiate the sweep and a single trace will be presented on the screen. After this sweep is complete, the A Sweep Generator is "locked out" until reset. The READY indicator lights when the A Sweep Generator circuit has been reset and is ready to produce a sweep; it goes out after the sweep is complete. To prepare the circuit for another single-sweep display, press the PUSH TO RESET button again.

A Trigger Holdoff

The A TRIG HOLDOFF control provides the ability to obtain stable triggered displays when triggering on a periodic or irregular signals (such as complex digital words). To use the control, first obtain the most stable presentation possible by adjusting the remainder of the A Trigger controls in the normal manner. Now, rotate the A TRIG HOLDOFF control clockwise until any remaining instability is eliminated.

In the B ENDS A (fully clockwise) position of the control, A Sweep is reset at the end of B Sweep. This provides the fastest sweep repetition rate when operating in a delayed sweep mode which, in turn, provides maximum display intensity (useful when viewing low repetition rate signals).

Horizontal Mode of Operation

There are basically two modes of operation for the internal horizontal sweep system. These are delayed and non-delayed. X-Y operation is reserved for discussion at a later time.

Non-Delayed Mode. In the A position of the HORIZ DISPLAY switch, the time base displayed is the A Time Base derived from the A Sweep Generator. The sweep rate of the display is determined by the setting of the A TIME/DIV switch. This is the only non-delayed mode of operation.

Delayed Mode. The B Sweep (delayed sweep) is operable in the MIX, A INT, and B DLY'D positions of the HORIZ DISPLAY switch. The A Sweep rate along with the

DELAY-TIME POSITION dial setting determines the time that the B Sweep is delayed. The sweep rate of the delayed portion is determined by the B TIME/DIV switch setting.

In the A INT position, the time base displayed will be the A Time Base as in the Non-Delayed Mode but additionally it will be intensified or brightened along some portion of its length. The intensification coincides with the time the B Sweep is running and is approximately equal to 10 times the setting of the B TIME/DIV switch. The amount of delay time between the start of A Sweep and the intensified portion is determined by the setting of the A TIME/DIV switch and the DELAY-TIME POSITION dial.

When the HORIZ DISPLAY switch is set to B DLY'D only the intensified portion (as viewed in the A INT position) is displayed on the screen at the sweep rate indicated by the B TIME/DIV switch.

The MIX position of the HORIZ DISPLAY switch provides a CRT display containing more than one time factor on the horizontal axis. The first part of the display will be at a sweep rate set by the A TIME/DIV switch and for a time duration determined by the setting of the DELAY-TIME POSITION control. The latter part of the display will be at a sweep rate set by the B TIME/DIV switch.

Horizontal Sweep Rates

The A AND B TIME/DIV AND DELAY TIME switches select calibrated sweep rates for the Sweep Generators. The A VAR control provides continuously variable sweep rates between the settings of the A TIME/DIV switch. Whenever the UNCAL light is on, the sweep rate of the A Sweep Generator is uncalibrated. The light is off when the A VAR control is set to the calibrated detent.

The sweep rate of the A Sweep Generator is bracketed by the two black lines on the clear plastic outer flange of the TIME/DIV switch. The B Sweep Generator sweep rate is indicated by the dot on the B TIME/DIV knob. See Fig. 13. When the dot on the inner knob is set to the same position as the lines on the outer flange, the two lock together and the sweep rate of both sweep generators is changed at the same time. However, when the B TIME/DIV knob is pulled outward, the outer flange is disengaged and only the B Sweep Generator sweep rate is changed. This allows changing the delayed sweep rate without changing the delay time determined by the A Sweep Generator.

The accuracy specifications for the horizontal sweeps apply over the full ten horizontal divisions. Therefore, accurate time measurements do not have to be limited to the center graticule divisions but can be made anywhere within the graticule area.

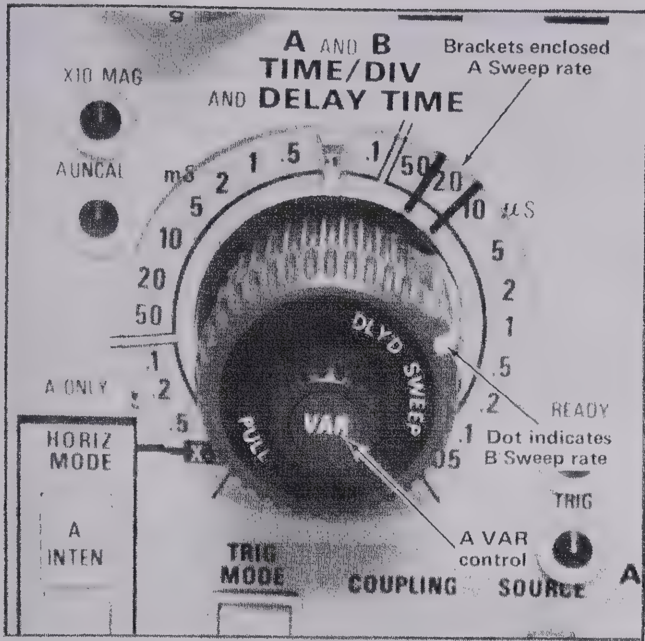


Fig. 13. A and B TIME/DIV switch.

Sweep Magnification

The sweep magnifier expands the sweep by a factor of ten. The center division of the unmagnified display is the portion visible on the screen in magnified form. The equivalent length of the magnified sweep is more than 100 divisions. Any 10-division portion of the magnified sweep can be viewed by adjusting the horizontal POSITION control to bring the desired portion into the viewing area.

To use the magnified sweep, first move the portion of the display which is to be expanded to the center of the graticule. Then set the X10 MAG switch to the on (button in) position. Use the horizontal POSITION control to move the magnified portion to the desired position. The X10 MAG indicator light located to the left of the TIME/DIV switch is on whenever the magnifier is on.

When the X10 MAG switch is set to on, the sweep rate is determined by dividing the TIME/DIV switch setting by 10. For example, if the TIME/DIV switch is set to .5 μs, the magnified sweep rate is 0.05 microsecond/division. The magnified sweep rate is a calibrated sweep rate when the UNCAL light is off, and must be used for all time measurements when the X10 MAG switch is set to on.

X-Y Operation

In some applications, it is desirable to display one signal versus another (X-Y) rather than against time (internal sweep). The X-Y position (fully counterclockwise) of the A AND B TIME/DIV switch provides a means for applying an external signal to the horizontal amplifier for this type of display.

When the TIME/DIV switches are fully counterclockwise to the X-Y position, the horizontal (X-axis) deflection is provided by the signal connected to the CH 1 OR X input connector and the vertical deflection is provided by the signal connected to the CH 2 OR Y input connector (CH 2 pushbutton must be pressed). The calibrated X-axis deflection is indicated by the CH 1 VOLTS/DIV switch; calibrated Y-axis deflection is indicated by the CH 2 VOLTS/DIV switch. For X-Y operation, the Horizontal POSITION control provides X-axis positioning and the CH 2 POSITION control provides Y-axis positioning.

Do not exceed the horizontal scan area of the graticule in the X-Y mode of operation. This mode can be used to measure phase differences of signals up to about 50 kilohertz in frequency. Above this frequency, the inherent phase shift in the system makes phase measurement difficult. To aid in interpreting lissajous displays, refer to the reference books listed under Applications.

Output Signals

A and B + GATE. The A and B + GATE output connectors (on instrument rear panel) provide a positive-going rectangular output pulse coincident with the sweep time of the respective sweep generator. This rectangular pulse is about five volts in amplitude (into high-impedance loads) with a pulse duration the same as the respective sweep.

Channel 1 Output. The CH 1 VERT SIGNAL OUT connector provides a sample of the signal connected to the CH 1 OR X input connector. Output amplitude is approximately 50 millivolts per division of display deflection when connected to a high-impedance load (25 millivolts per division into a 50 Ω load).

Intensity Modulation

Intensity (Z-axis) modulation can be used to relate a third item of electrical phenomena to the vertical (Y-axis) and the horizontal (X-axis) coordinates without affecting the wave shape of the displayed signal. The Z-axis modulating signal applied to the CRT circuit changes the intensity of the displayed waveform to provide this type of display. "Gray scale" intensity modulation can be obtained by applying signals which do not completely blank the display. Large amplitude signals of the correct polarity will completely blank the display. The sharpest display is provided by signals with a fast rise and fall. The voltage amplitude required for visible trace modulation depends on the setting of the INTENSITY control. At normal intensity level, a five-volt peak-to-peak signal produces a visible change in brightness.

Time markers applied to the EXT Z AXIS input connector provide a direct time reference on the display. With uncalibrated horizontal sweep or X-Y mode operation, the time markers provide a means of reading time directly

from the display. However, if the markers are not time-related to the displayed waveform, a single-sweep display should be used (for internal sweep only) to provide a stable display.

Calibrator

The one-kilohertz square-wave Calibrator of the 465 provides a convenient signal source for checking basic vertical gain. However, to provide maximum measurement accuracy, the adjustment procedure given in the Calibration section of the Instruction Manual should be used when recalibrating the unit. The Calibrator output signal is also very useful for adjusting probe compensation as described in the probe instruction manual.

Voltage. The Calibrator provides an accurate peak-to-peak square-wave voltage of 0.3 volts. The output resistance of the circuit is low enough to almost totally eliminate the effects of external loading. The output voltage is accessible by touching the tip of the probe to the current loop available on the front panel of the instrument.

Current. The current loop provides a 30 milliampere peak-to-peak square-wave current which can be used to check and calibrate current-measuring probe systems. This current signal is obtained by clipping the probe around the current loop. The arrow by the probe loop indicates conventional current flow (from + to –).

Frequency. The repetition rate of the output signal is approximately one kilohertz. The accuracy is not exact enough to allow the signal to be used for more than approximating horizontal timing.

Wave Shape. The square-wave output signal of the Calibrator can be used as a reference wave shape when checking or adjusting the compensation of passive, high-resistance probes. Since the square-wave output from the Calibrator has a flat-top, any distortion in the displayed waveform is due to misadjustment of probe compensation.

OBTAINING BASIC DISPLAYS

Introduction

The following instructions will allow the operator who is unfamiliar with the operation of the 465 to obtain the basic displays commonly used. Before proceding with these instructions, preset the instrument controls as follows:

Vertical Controls

VERT MODE Switch	CH 1
VOLTS/DIV Switches	Proper Position determined by amplitude of signal to be applied.
VOLTS/DIV VAR Controls	Calibrated detent.
Input Coupling Switches	AC
Vertical POSITION Controls	Midrange
20 MHz BW Switch	Not limited
INVERT Switch	Button out
INTENSITY Control	Fully Counterclockwise
FOCUS Control	Midrange
SCALE ILLUM Control	Midrange

Trigger Controls (both A and B if Applicable)

SLOPE Switch	+
LEVEL Control	0
SOURCE Switch	NORM
COUPLING Switch	AC
TRIG MODE Switch	AUTO
A TRIG HOLDOFF Control	NORM

Horizontal Sweep Controls

TIME/DIV Switches	Locked together at 1 ms
A TIME/DIV VAR	Calibrated detent
HORIZ DISPLAY Switch	A
X10 MAG Switch	Off (button out)
POSITION Control	Midrange

Normal Sweep Display

1. Set the POWER switch to on (button out). Allow several minutes for instrument warmup.

2. Connect the external signal to the CH 1 input connector.

3. Advance the INTENSITY control until the display is visible. If the display is not visible with the INTENSITY control at midrange, press the BEAM FIND pushbutton and adjust the CH 1 VOLTS/DIV switch until the display is reduced in size vertically; then center the compressed display with the vertical and horizontal POSITION controls; release the BEAM FIND pushbutton. Adjust the FOCUS control for a well-defined display.

4. Set the CH 1 VOLTS/DIV switch and CH 1 POSITION control for a display which remains in the display area vertically.

5. Adjust the A Trigger LEVEL control for a stable display.

6. Set the A TIME/DIV switch and the horizontal POSITION control for a display which remains in the display area horizontally.

Magnified Sweep Display

1. Preset the instrument controls and follow steps 1 through 6 for obtaining a Normal Sweep Display.

2. Adjust the horizontal POSITION control to move the area to be magnified to within the center graticule division of the CRT. If necessary, change the TIME/DIV switch setting so the complete area to be magnified is within the center division.

3. Set the X10 MAG switch to the on position (button in) and adjust the horizontal POSITION control for precise positioning of the magnified display.

Delayed Sweep Displays

1. Preset the instrument controls and follow steps 1 through 6 for obtaining a Normal Sweep Display.

2. Set the HORIZ DISPLAY switch to A INT and the B Trigger SOURCE switch to STARTS AFTER DELAY.

3. Pull out the B TIME/DIV switch knob and turn clockwise so the intensified zone on the display is the desired length. Adjust the INTENSITY control to achieve the desired display brightness.

4. Adjust the DELAY-TIME POSITION dial to position the intensified zone to the portion of the display to be delayed.

5. Set the HORIZ DISPLAY switch to B DLY'D. The intensified zone on the display noted in step 3 is now being displayed in delay form. The delayed sweep rate is indicated by the dot on the B TIME/DIV switch knob.

6. For a delayed sweep display that will exhibit less jitter, set the B Trigger SOURCE switch to the same position as the A Trigger SOURCE switch and adjust the B

Trigger LEVEL control for a stable display. If the A Trigger SOURCE switch is in the LINE position, a sample of the line voltage will have to be supplied to the B Trigger circuit externally.

Mixed Sweep Display

1. Preset the instrument controls and follow steps 1 through 6 for obtaining a Normal Sweep Display.

2. Pull out on the B TIME/DIV switch knob and turn clockwise to the desired sweep rate. Adjust the INTENSITY control to achieve the desired display brightness.

3. Set the HORIZ DISPLAY switch to MIX. The CRT display now contains more than one time factor on the horizontal axis. The first portion of the display is at the A Time Base sweep rate and the latter part is at the B Time Base sweep rate. The start of the B Time Base portion of the display can be changed by adjusting the DELAY-TIME POSITION control.

X-Y Display

1. Preset the instrument controls and turn the instrument power on. Allow several minutes for instrument warm-up.

2. Set the TIME/DIV switch to X-Y and the VERT MODE to CH 2. Apply the vertical signal to the CH 2 OR Y input connector and the horizontal signal to the CH 1 OR X input connector. The CH 2 POSITION control will provide vertical positioning and the Horizontal POSITION control will provide horizontal positioning.

3. Advance the INTENSITY control until the display is visible. If the display is not visible with the INTENSITY control at midrange, press the BEAM FIND pushbutton and adjust the CH 1 and CH 2 VOLTS/DIV switches until the display is reduced in size both vertically and horizontally; then center the compressed display with the POSITION controls; release the BEAM FIND pushbutton. Adjust the FOCUS control for a well-defined display.

USER'S CALIBRATION

General

To insure measurement accuracy, certain portions of the instrument's calibration should be checked before making the measurement. The following is a procedure for checking the basic measurement capabilities of the 465. See the Calibration section of the Instruction Manual for more detailed calibration information.

TRACE ROTATION Adjustment

Use steps 1 through 3 of the procedure for obtaining a Normal Sweep Display. Set the appropriate Input Coupling switch to GND so the display consists of an undeflected free-running trace. Adjust the TRACE ROTATION adjustment (located on the front-panel below the CRT) to align the trace with the center horizontal graticule line.

Vertical Gain

Obtain a Normal Sweep Display presentation of the calibrator square-wave voltage. Set the appropriate VOLTS/DIV switch to the 50 mV position and the Input Coupling to DC. Adjust the appropriate Channel GAIN adjustment for exactly 6 divisions of vertical deflection. Repeat this procedure for the other vertical channel.

Probe Compensation

Variations in total input capacitance and resistance occur with different combinations of oscilloscopes and probes. Therefore, most attenuator probes are equipped with adjustments to insure optimum measurement accuracy. Probe compensation is accomplished as follows:

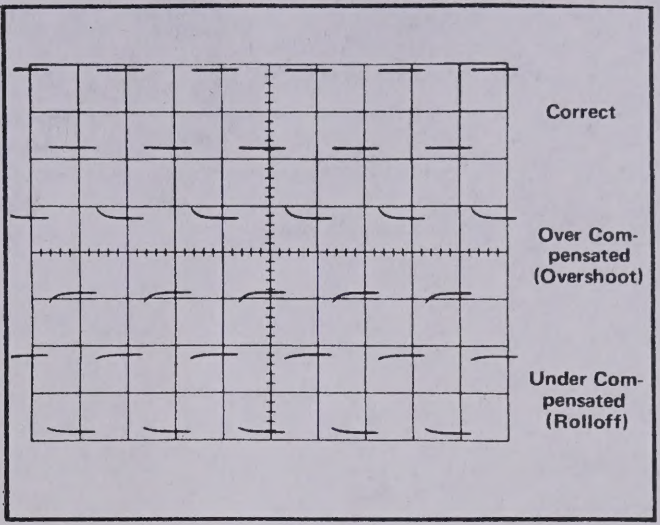


Fig. 14. Probe compensation.

Obtain a Normal Sweep Display presentation of the calibrator square-wave voltage. Set the appropriate VOLTS/DIV switch to the .1 V position and the Input Coupling to DC. Check the waveform presentation for overshoot or rolloff, and readjust compensation for flat tops on the waveforms if necessary. See Fig. 14.

Basic Timing Accuracy

Obtain a Normal Sweep Display presentation of some external accurate timing reference signal (such as time markers from a TEKTRONIX 2901 Time-Mark Generator). When viewing an accurate 1 kHz signal or 1 ms time marks, there should be one cycle or one time mark per division in the 1 ms position of the TIME/DIV switch. For a more complete timing check, refer to the calibration procedure given in the Instruction Manual.

External Horizontal Gain Accuracy

Use steps 1 through 3 of the procedure for obtaining Normal Sweep Display of the calibrator square-wave voltag waveform; then, set the TIME/DIV switch to X-Y. With th calibrator signal connected to the CH 1 OR X inpu connector and the CH 1 VOLTS/DIV switch set to 50 mV the CRT display should be two dots separated horizontall by exactly six divisions. Refer to the Calibration section o the Instruction Manual for more complete calibratio information.